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TECHNICAL REPORT NO. 11738

INFRARED NON-DESTRUCTIVE ANALYSIS OF SOLID RUBBER ROAD WHEELS

U.S. ARMY TANK-AUTOMOTIVE COMMAND LABORATORIES

FEBRUARY 1973

by David K. Wilburn

AMSTA-RH

TACOM

MOBILITY SYSTEMS LABORATORY

U.S. ARMY TANK AUTOMOTIVE COMMAND Warren, Michigan

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PHYSICAL SCIENCE BRANCH
CONCEPT & TECHNOLOGY DIVISION
RESEARCH, DEVELOPMENT & ENGINEERING DIRECTORATE
U.S. ARMY TANK AUTOMOTIVE COMMAND

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ABSTRACT

Twenty-six used and rebuilt solid rubber road wheels were examined by an infrared temperature profiling technique during drum test exercise. The IR method was evaluated as a nondestructive means of predicting road wheel integrity by analysis of the circumferential temperature profile. The effectiveness of the temperature profiling method was determined by stripping the rubber from each wheel and visually evaluating the bond interface and rubber tread. Known defects comprising tread and sidewall cracks and rubber-metal interface delamination were artificially induced into rebuilt road wheels to evaluate the examination method. Left and right sidewall and tread area were examined simultaneously by use of three sensor heads which were mounted in a test rig positioned around the test wheel. Results indicate that the IR test technique has a capability of detecting cracks and chunking in the rubber tread, gross unbonds and interface delaminations, and large area entrapped foreign objects at the rubber-to-metal interface. Low bonds strength and small unbond areas less than one square inch were not detected. Defects located along the left sidewall interface area were more difficult to sense due to the wear flange and high thermal coupling into the metal sidewall which dissipated tread developed heat.

FOREWORD

This program is a Production Engineering Measures Project (PEMA) funded and directed thru the Army Materials and Mechanics Research Center, AMXMR-QA. The project was performed totally in-house within the Concept and Technology Division by the Physical Science Laboratory, Army Tank Automotive Command, Warren, Michigan, AMSTA-RH.

Inquires may be directed to the Commander, U. S. Army Tank Automotive Command, or the Army Materials & Mechanics Research Center, Watertown, Massachusetts.

LIST OF FIGURES

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ACKNOWLEDGEMENTS

The assistance of technicians from the Mechanical Function Group, AMSTA-RKAM, Mechanical Laboratory is acknowledged. Their support, based on past experience, during drum test operations and analysis of bond strength conditions in exercised wheels, assured an accurate interpretation of reported results.

SUMMARY

The infrared inspection technique as described in this report and performed during drum loading tests on solid rubber road wheels has the following capabilities:

(1) Detection of gross unbonds at rubber/metal interface of surface area 1 square inch or larger.

(2) Detection of splice separation, or tread/sidewall superficial cuts or tears that extend across the tread or sidewall surface.

(3) Detection of large entrapped foreign materials at interface zone where bond has been lost.

(4) Detection of chunking in sidewall or tread area.

(5) Identification of active (growing) unbonds at interface as compared to static (stable) unbond areas.

(6) Based on circumferential temperature profile, to estimate extent and location of defect type detected.

(7) Identification of out-of-round wheels.

Results of tests as described in this report indicate that the IR technique was not able to sense or predict the following defect types or conditions:

(1) Low bond strength at tread/wheel interface.

(2) Inclusion of foreign materials at interface zone where bond integridy is intact or area of object is less than 1 square inch.

(3) Non-homogenity in tread or tread inclusions.

(4) Prediction of latent defects in tread or interface zone prior to real development.

(5) Cleat puncture.

In addition, the wear flange produced a degredation of sensitivity at the circumferential flange edge due to increased thermal conductivity from flange area into wheel body.

RECOMMENDATIONS

1. It is recommended that the infrared inspection technique be considered as a supplementary examination procedure to the standard MIL-T-3100B drum test.

INTRODUCTION

The M-113 solid rubber road wheel has been and remains a high demand item in the tank automotive inventory. Inspection and acceptance of new and rebuilt wheels fall within the jurisdiction of Military Specification MIL-T-3100B. Because both new and rebuilt wheels have experienced high failure rates in use, the Quality Assurance Directorate thru the TACOM SIMO office was directed to initiate studies leading to the use of more advanced inspection techniques. Based on past experience in IR/NDT techniques, the Physical Science Branch of the Mobility Systems Laboratory, USATACOM was funded thru AMMRC, Watertown Arsenal to apply lessons learned in the IR diagnostic pneumatic tire programs to the inspection of M113 roadwheels.[1, 2]

Historically, variations of the infrared nondestructive diagnostic test have been performed on an experimental or research basis for several years.[1, 2, 3, 4] Results of these tests as performed by both tire manufacturer and various government agencies are sufficiently optomistic to warrent consideration of the IR method as a potential candidate for indorsement as one of the standard test techniques. Based on the similarity of test requirements for both pneumatic tires and solid rubber tread wheels, an initial analysis indicated the advisability of applying the same IR test scheme developed for pneumatic tires to the roadwheel.

RESULTS

Instrumentation

The infrared circumferential profiling systems consisted of a three channel "Sensors Incorporated" model 804 Tire Defect Sensor System modified for expanded low frequency response. The modification was necessary since the drum test is performed at 10 mph, which could possibly result in a large defect producing a thermal pulse of 2 to 5 Hz. Since the standard "Sensors" unit has a frequency response of between 7 and 20, 000 Hz, the expanded low frequency response was necessary to assure adequate sensitivity to low frequency signals.

The characteristics of the model 804 system as published by the manufacturer are as shown in Table I.

TABLE I

OPTICAL & ELECTRICAL CHARACTERISTICS OF MODEL 804 TIRE DEFECT SENSOR

Detector	Thermopile
Collector Optics	Reflective
Collector Optics Diameter	2 Inches
Field of View on Target	1/2 x 1/2 inch
Wavelength Pass	0.8 - 40 Micrometers
Temperature Sensitivity	$0.01V/^{\circ}F$
Response, Temperature Difference	$1^{\circ}F$
Response Time	50 Milliseconds
Frequency Response	1 - 20,000 Hz
Environmental Operating Temperature	-40 to $+160^{\circ}F$

The three channel system is illustrated mounted on the drum exercise machine in Figure 1. An overall view of the drum dynamometer is shown in Figure 2. One sensor "looks" at the tread area, and the other two at left and right sidewalls, respectively. An optical trigger (photocell/preamplifier) mounted on the left sidewall sensor head, and shown in Figure 3, senses a white radial trigger mark painted at the serial number. The output of the trigger preamplifier fed channel 2 of the recording oscilloscope so that X-scan stability could be achieved to display 360^{o} of tire circumference. The oscilloscope, switching network and main amplifier are illustrated in Figure 4. A polaroid camera was used to provide a hard copy of the oscilloscope trace.

PROCEDURES

Each raod wheel was visually inspected for any mechanical fault which could possibly create a safety hazard when under load, or any evidence that a catastrophic failure could take place. The wheels were then cleaned, mounted on a spindle and positioned in the drum carriage. The white radial trigger mark was painted at the serial number and a black emissivity coating spray paint used to normalize the rubber surface if the initial cleaning did not remove surface dirt or mold chemicals. The rubber surfaces of the test wheel were then inspected for superficial defects or suspected areas where failures could occur and a record was made of the findings. An initial "spin-up" of the wheel was performed to determine balance or out of round. On the rebuilt wheels, out of round conditions were remedied by grinding the tread to achieve an acceptable round. *

The wheel was loaded to the specification value of 2095# at 10 mph. For used wheels, a modified specification test was performed consisting of 4 hours of drum operation at existing ambient temperature conditions. Data was recorded at 30 minutes after start of test, after 2 hours and at 4 hours. For the rebuilt wheels, the standard MIL-T-3100B, paragraph 4. 5. 3 test was performed with interim observation made at 30 minutes after start of test, after 2 hours, 4 hours, 8 hours and upon completion (48 hours). The wheel was then again examined visually and a record was made of any changes in rubber condition. After removal from the drum machine, the rubber was stripped from the wheel and a detailed examination, photograph and drawing made of the interface area.

TEST SPECIMENS - DESCRIPTIONS

Twenty-seven used and rebuilt M-113 road wheels, 24 x 2-1/8 inches, part number 8763350 were received for examination. The wheels are identified and listed in Table II. Fourteen of the wheels were run for drum test purposes, four were subject to adhesion tests only, two were judged not suitable for drum test, three were submitted for other tests and four were inspected but not run.

* per paragraph 4. 5. 2. 2 of Specification MIL-T-3100B

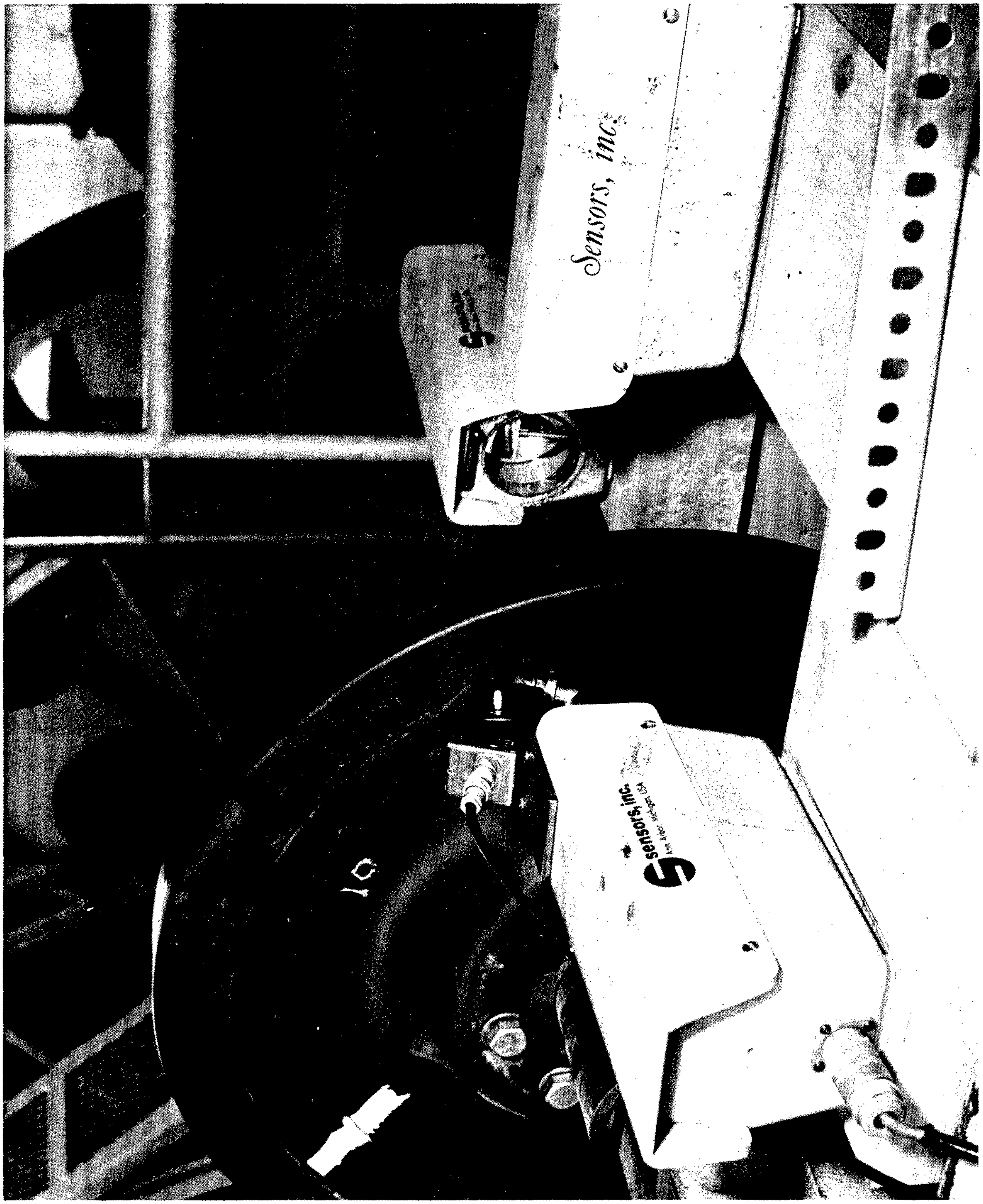

Figure 1 - Three Channel Infrared Sensor Package Viewing Road Wheel

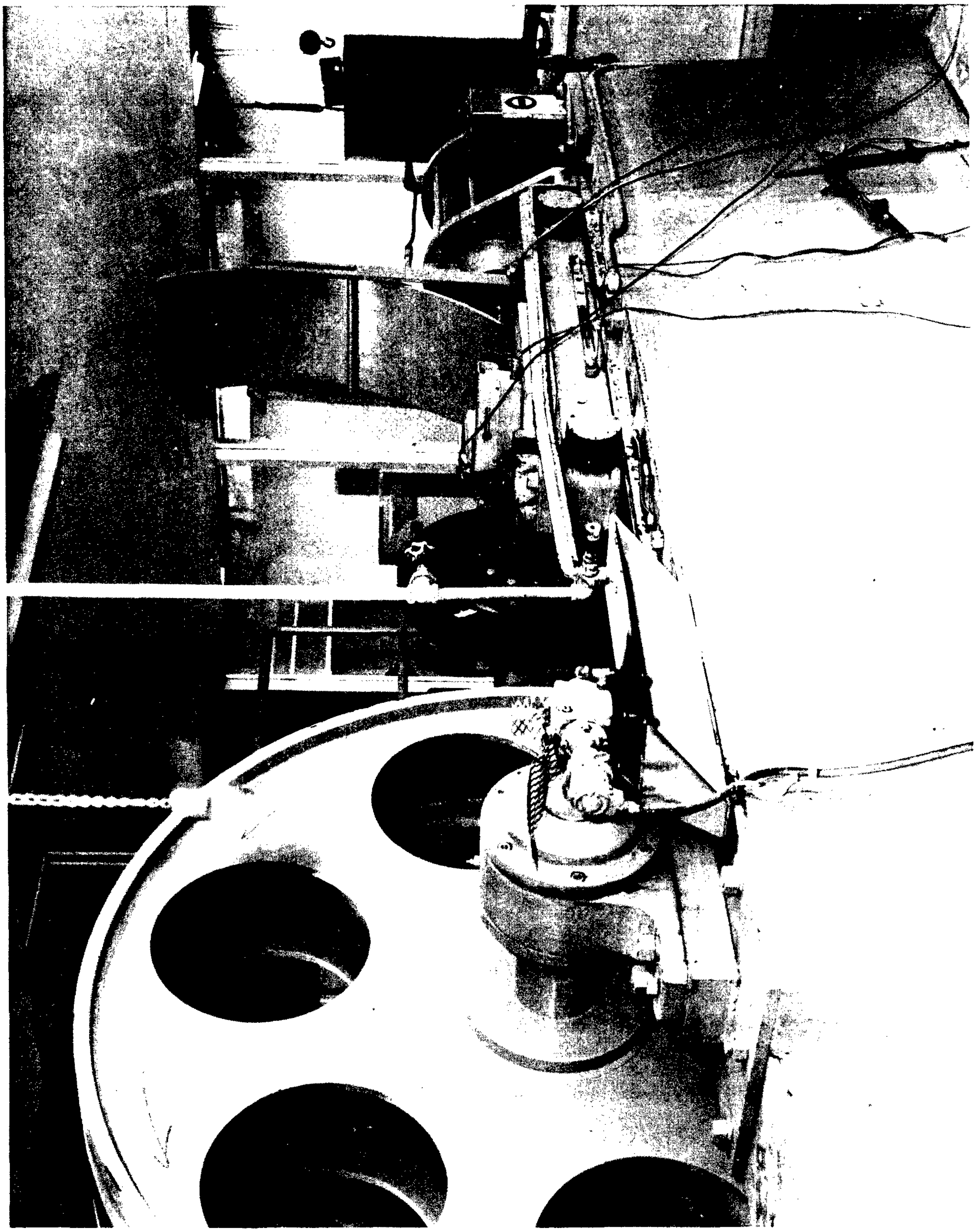

Figure 2 - Road Wheel Drum Dynamometer

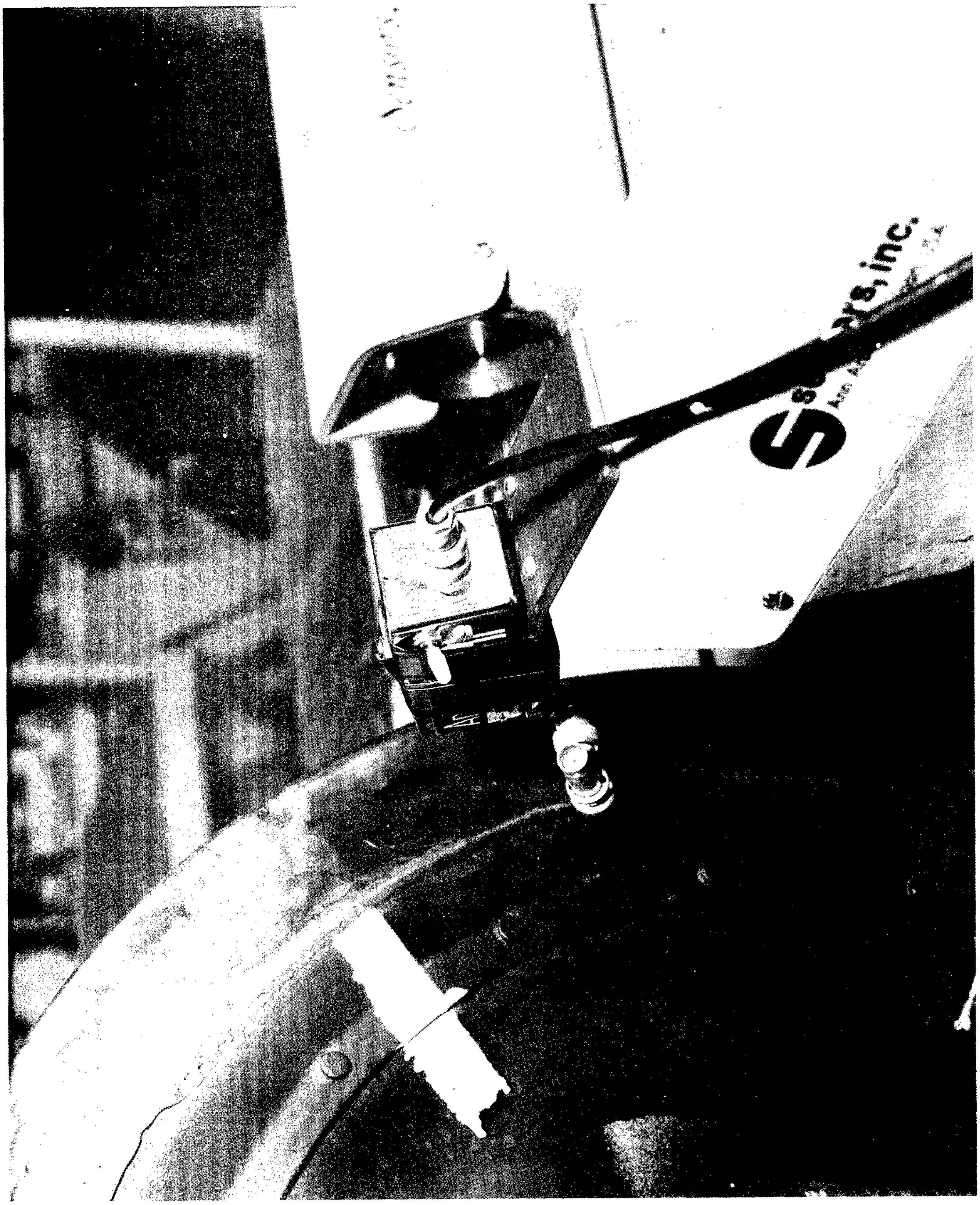

Figure 3 - Photocell Amplifier Location Viewing Trigger Mark

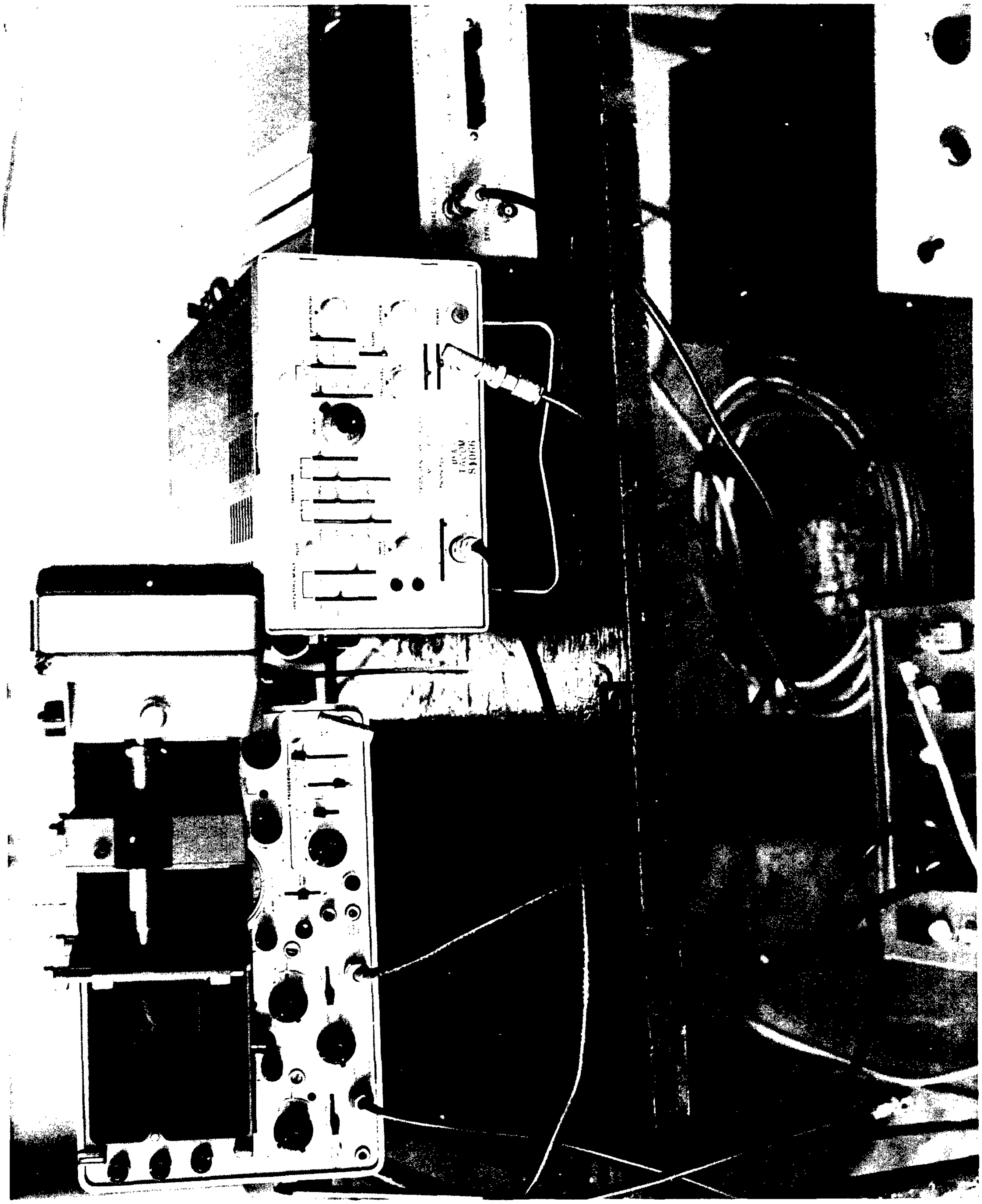

Figure 4 - Electronics Comprising Oscilloscope, Camera, Amplifier and Switch Box

RESULTS

Results are presented in figure and table form in support of the following program objectives;

(1) The evaluation of the thermal (infrared) method of inspecting road wheels for internal and superficial defects.

(2) A description of typical failures evidenced in used and rebuilt road wheels.

The infrared techniques used in the road wheel inspection program were initially developed during two pneumatic tire research projects.[1,2] Only a minimal amount of new research was necessary to apply the IR pneumatic tire inspection techniques to the analysis of road wheels. Since the road wheel drum test is conducted at 10 mph, it was necessary to expand the low frequency response of the pre-amplifiers in the sensor heads to provide for maximum sensitivity against gross defects which gave rise to thermal signals of a few cycles frequency response. No other major measurement or analysis changes were made from existing techniques previously developed.

To develop competence in inspecting the solid rubber road wheels, known defects, either artificially induced or discovered in used wheels after removal of the rubber tread were used to develop a series of standard thermal patterns.[5,6] As typical defects were observed and identified in varying size and positions, a degree of confidence was generated in the analysis of the oscilloscope traces.

Figures 5 thru 9 illustrate some typical thermal profile "signature patterns" which are representative of common defects evident in used wheels. The defects are described as follows:

Figure Number	Signature Identified
16	Gross Unbalance
	Side "Chunking"
	Cut in Tread
17	Cut in Sidewall
	Gross Unbond at Interface, 15 sq. in.
	Minor Unbond at Interface, 5 sq. in.
18	Small Unbond at Interface, 2 sq. in.

Figure Number	Signature Identified
	No defects detected
19	Thermal Transfer
	To Tread and Left Sidewall area
20	Active Heat Producing Unbond
	Passive Dormant "Cold" Unbond

Description of Defects and Related Thermal Patterns:

Although unbalance is not considered a major defect, the large thermal difference that is produced could either obscure a smaller defect induced pulse or be misinterpreted as a gross interface defect. Unbalance or out of round is, however, easy to interpret since it appears as a single cycle thermal wave of large temperature difference. Surface chunking or texture differences (Figure 5, second trace) appear as a high frequency signal of fairly uniform temperature intensity. Tread and sidewall cuts show as sharp thermal pulses. Gross unbond defects at interface are large "cool" spots; smaller unbonds appear as narrow cool pulses.

Where large temperature differences are produced, there may be "thermal telegraphing" to adjacent areas. That is, in Figure 8 two defects located in the left shoulder/sidewall area produce such intense "cool" pulses that they are also seen in the right shoulder/sidewall area.

A more difficult interpretation is between a small thermally intense hot spot (pulse) and an equally intense cold pulse apparently both produced by an interface unbond. Based on examination of this type of unbond after stripping, it is concluded that "hot pulse" unbonds are growing in size and are in a high friction area. "Cold pulse" unbonds may be dormant and not increasing in size. In addition, "cold spots" may have been caused by a local effect such as solvent residue or foreign matter and after the initial unbonding may not spread beyond the effect size.

Infrared Analysis During Drum Test - 11 Test Wheels

After the initial "learning period", eleven road wheels were subsequently selected from 27 test samples representing six manufacturers' products. The sample wheels are identified in Table II. Figures 10 thru 20 are composit illustrations containing the following information:

TABLE II

IDENTIFICATION OF TEST WHEELS

MANUFACTURER	CONDITION	SERIAL NUMBER	I.D. NUMBER	TYPE OF TEST	REMARKS
Red River	Rebuilt	-	10	62 Hr Drum	Run to destruction
" "	"	-	11	4 Hr Drum	Out of Round
" "	"	-	12*	48 Hr Drum	
" "	"	-	13*	48 Hr Drum	
Firestone	Used	22337	21	4 Hr Drum	
"	"	"	20	4 Hr Drum	
"	"	"	22	No Test	
"	"	350880	19	4 Hr Drum	
		350880	18	No Test	
Goodyear (Los Angeles)	Used	89611	2	Not Run	Adhesion Only
" "	"	89611	3	Not Run	Wear Flange Sectioning
" "	"	89611	4	No Test	
" "	"	89611	5	4 Hour Drum	
" "	"	89611	1	Not Run	Adhesion Only
Goodyear (St Mary's)	Used	08754	8	4 Hr Drum	
" "	"	08754	7	4 Hr Drum	
" "	"	08754	9	No Test	
" "	"	08754	6	Not Run	Adhesion Only
Vinco (CBR)	Used	CBR 873350	14	Not Run	Poor rubber bond condition
" "	"	CBR "	15	4 Hr Drum	
" "	"	CBR "	16	4 Hr Drum	
" "	"	CBR "	17	Not Run	Submitted to AMSTA-QA
OBER-RAMSTADT	Used	EOR-EBZ	24	4 Hr Drum	
" " "	"	EOR-EEZ	25	Failed**	
" " "	"	EOR-EKZ	26	Not Run	Poor rubber bond condition
" " "	"	EOR-EGZ	27	Not Run	Adhesion Only

*Tread buffed to assure less than .1" radial run-out

**Rubber separated from wheel after 30 minutes running

TABLE III

SUMMARY OF DEFECTS DEVELOPED IN DRUM TEST WHEELS

Wheel No.	Figure No.	Hours Run	Type of Failure
5	10	4	Unbonds at interface and under 100% wear flange, erosion.
7	11	4	Unbonds at interface . Erosion
8	12	4	Unbonds at interface and under 50% wear flange. Track guide damage. Adhesive feathering.
12	13	48	Unbonds at interface and under 100% wear flange.
13	14	48	Unbonds at interface and under 100% wear flange. Trapped foreign material.
15	15	4	Unbonds at interface.
16	16	4	No defects.
19	17	4	Unbonds at interface and under 50% wear flange. Track guide damage.
20	18	4	No defects.
21	19	4	Unbonds at interface and under 10% wear flange. Erosion.
24	20	4	Unbond at interface. Signs of solvent residue.

(1) Photograph of rubber-metal interface after rubber was stripped from wheel

(2) Drawing of interface area outlining location and size of defects

(3) Thermal circumferential temperature profiles for right sidewall, tread and left sidewall

(4) Close-up photograph of major defect area

The four hour drum tests were a modified procedure derived from Military Specification MIL-T-3100B.

The composit figures allow direct comparison to be made between the thermal signature pattern and interface defects illustrated in the drawing or shown in the tread interface photograph. A summary of the type of defects developed during the drum test program for 11 test wheels is shown in Table III.

A critique of the results (determined from Figures 10 thru 20) is shown in Table IV. Each defect is numbered, identified and listed according to size and degrees rotation from the optical trigger mark. Based on the interface defects exposed when the rubber was stripped from the wheel, comparison can be made on how closely characteristic thermal patterns presented in the thermal profile correspond to actual defects. An analysis of each set of thermal profiles generated during drum test exercise indicates that 56% of the real defects of at least 1 square inch were sensed.

A second consideration is the number of "false signal" indications evident in each thermal profile set. That is, defects which were predicted by the IR analysis to be present but which could not be found or identified after the wheel was stripped and cut apart. Table V lists the number of false signal indications. Out of eleven wheels studied, there were five indications of 1 or more false signals which could not be verified by subsequent sectioning.

TABLE IV

CRITIQUE OF INFRARED TECHNIQUE OF INSPECTING M113 ROAD WHEELS

Test Wheel Number	Number Defects Identified from Stripped Rubber	Size & Location of Defect No.	Location	Size in.	Results of IR Analysis *	% Accuracy
5	5	1	80°	3/4 x 3-1/2	MD	
		2	95°	2 x 8	PD	60
		3	185°	2 x 9	PD	
		4	225°	3/4 x 3	ND	
		5	$0\text{-}360^{\circ}$	1/2 x 63	ND	
7	6	1	70°	3/4 x 1/2	ND	
		2	90°	1/2 x 1	ND	
		3	170°	1/2 x 3	ND	
		4	190°	3/4 x 1-1/2	PD	50
		5	270°	2 x 10	PD	
		6	350°	1 x 4	MD	
8	6	1	45°	1/2 x 2	MD	
		2	90°	3/4 x 12	PD	
		3	135°	1/2 x 1	ND	
		4	180°	3/4 x 5	MD	87
		5	225°	3/4 x 2-1/2	MD	
		6	270°	3/4 x 4	PD	
12	2	1	45°	1 x 2-1/2	PD	100
		2	225°	3/4 x 2-1/2	PD	
13	3	1	160°	3/4 x 2	ND	
		2	190°	3/4 x 3/4	ND	
		3	$0\text{-}360^{\circ}$	1/2 x 63	ND	28
	Induced Defects	Needle hole, tread 45°			ND	
		Cut, R/Sidewall, 90°			MD	50
		Cut, Tread, 180°			PD	
		Cut, L/Sidewall, 270°			ND	
15	3	All defects less than 1 sq. in.				-
16	0	No Unbonds				-
19	4	1	90°	1/2 x 1	ND	
		2	125°	1/2 x 1-1/2	ND	
		3	170°	1/2 x 1/2	ND	
		4	180°	1/2 x 3/8	ND	16
		5	265°	1/2 x 8	PD	
		6	350°	3/4 x 3	ND	
20	0	No Unbonds				
21	4	1	90°	1/2 x 1/2	MD	
		2	255°	3/4 x 2	MD	
		3	270°	3/4 x 2	MD	
		4	325°	3/4 x 2	PD	100
24	1	1	$0\text{-}360^{\circ}$	1 x 63	PD	100
						56 Average

* PD = Positive Detection
MD = Marginal Detection
ND = Not Detected

TABLE V

ANALYSIS OF "FALSE SIGNAL" INDICATIONS

Test Wheel Number	False Signal Indications
5	None
7	None
8	None
12	One
13	None
15	One
16	None
19	None
20	Two
21	One
24	Three

DISCUSSION

Some of the immediate observations with respect to the potential of the IR inspection method are:

(1) The wear flange side of the wheel is a difficult area to inspect due to high thermal conduction from this area into the adjacent metal sidewall face of the wheel.

(2) Out-of-balance wheels produce a large thermal unbalance which appears as a temperature induced sine wave. This broad thermal wave may interfere or obscure less intense defect produced "hot" or "cold" pulses making positive recognition difficult.

(3) Surface "chunking" of the rubber sidewall on the wear flange side in used wheels produces high frequency thermal noise which may interfere or obscure defect produced "hot" or "cold" pulses making positive recognition difficult.

Some of the immediate observations with respect to the type of defects discovered in the rebuilt and used road wheels are:

(1) The area under the wear flange is a potentially acute zone for the generation of interface unbonds

(2) Rubber-to-metal interface unbonds comprise the most common type of defect observed in used and rebuilt wheels.

(3) Close examination of the interface area surrounding the unbond zone shows evidence of foreign trapped materials which appear to have triggered the start of the unbond. These materials have been tentatively identified as follows:

   (a) Solvent residue under and around the circumference of the wear flange.

   (b) Road chemicals and/or solvents forced past the wear flange rivit edge into the rubber bond area immediately under the flange.

   (c) Foreign material, such as brush bristles, dirt, etc, trapped at the interface during manufacture.

   (d) Feathering of adhesive in application along shoulder edges of metal tread area (absence of adhesive).

(e) Erosion of road debris under rubber tread edge or past wear flange zone penetrating rubber bond.

(f) Track guide puncture forcing foreign debris into rubber tread.

No rubber inhomogeniety was discovered although there is evidence that porosity or trapped foreign objects within the rubber tread have been encountered in the sectioning of entire tread bodies.[7] The presence of foreign objects within the interface zone does not always mean there is or will be an unbond in that area. In several instances where the rubber was peeled from the wheel, sufficient bond strength was indicated in the presence of a foreign object imbedded in the interface.

Based on the types of defects discovered in used wheels, it appears possible to manufacture a series of test wheels with known size, location and defect type for NDT evaluation purposes.

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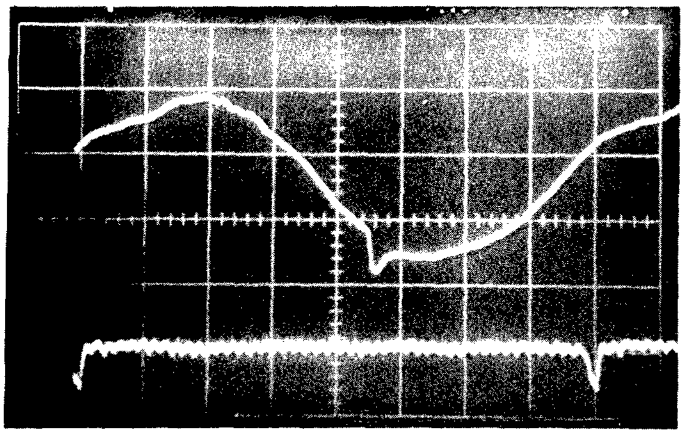
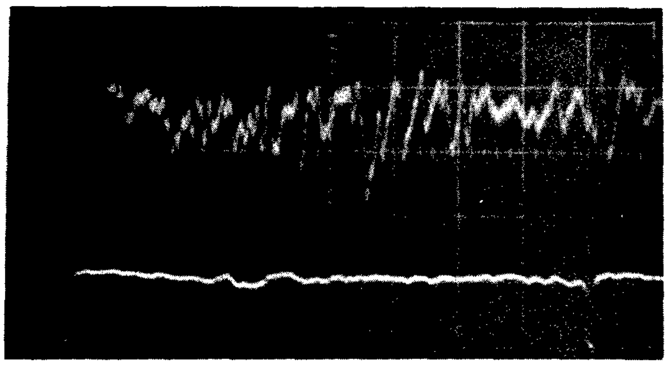


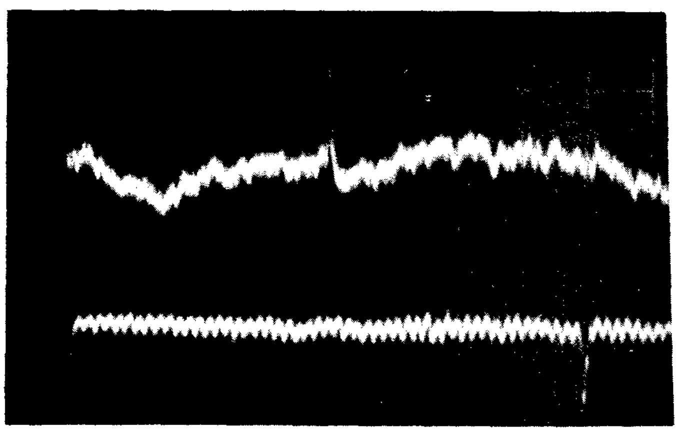
Test Wheel # 11
Right Sidewall

Gross Unbalance (out of round)



Test Wheel # 24
Left Sidewall

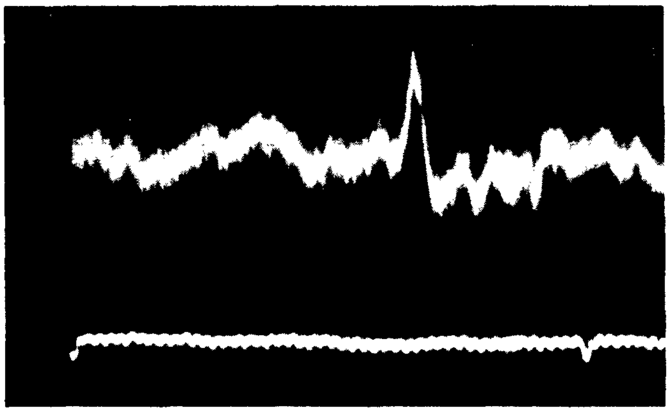
Sidewall "Chunking"



Test Wheel # 13
Tread

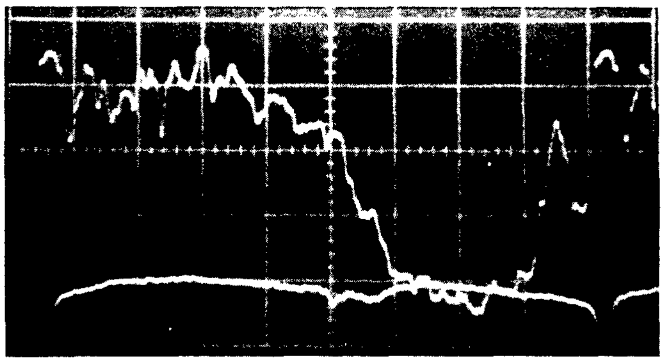
Tread Cut at 180°

Figure 5 - Typical Circumferential Thermal Patterns Observed In M-113 Road Wheels



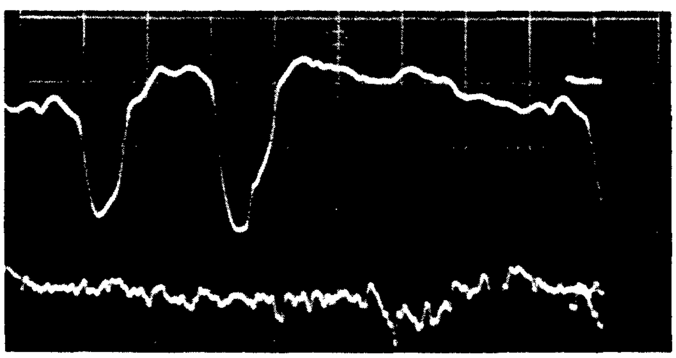
Test Wheel # 12
Right Sidewall

Sidewall Cut at 240^{o}



Test Wheel # 19
Right Sidewall

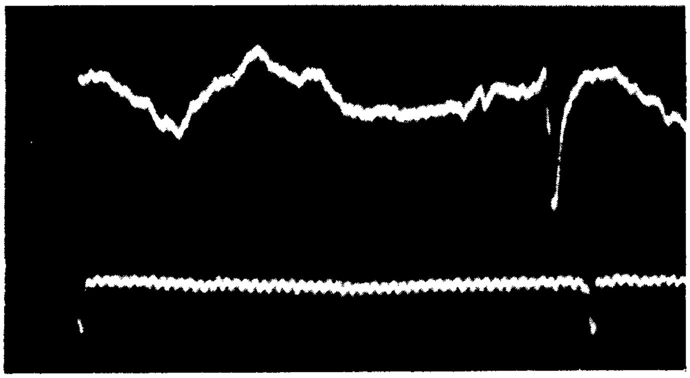
Gross Unbond, 220^{o} to 310^{o}, 15 Square Inches Area



Test Wheel # 5

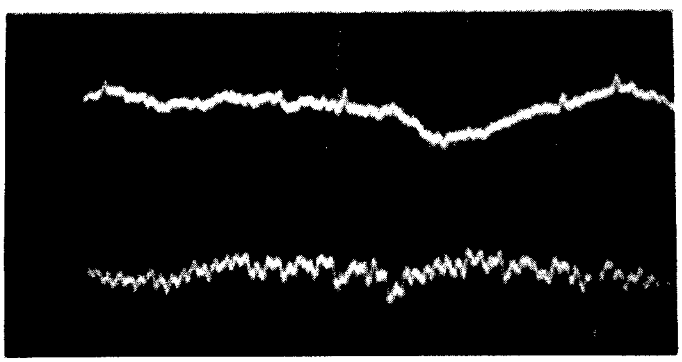
Minor Unbonds at 60^{o} and 150^{o}, 5 Square Inches
Area Each Unbond

Figure 6 - Typical Circumferential Thermal Patterns Observed
In M-113 Road Wheels



Test Wheel # 13

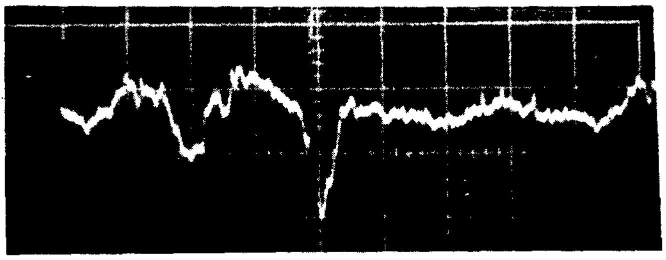
Small Unbond at 300°, 2 Square Inches Area



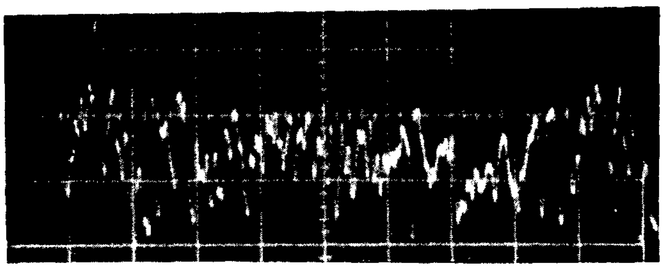
Test Wheel # 10

No Defects, Minimal Thermal Variations

Figure 7 - Typical Circumferential Thermal Patterns Observed In M-113 Road Wheels

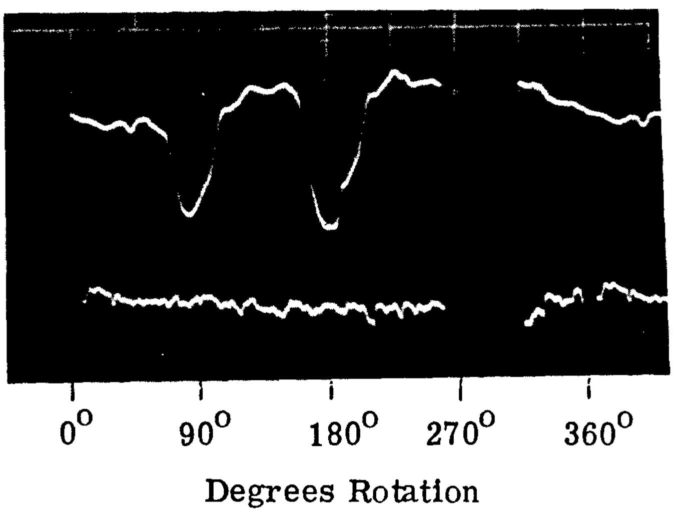


RIGHT SIDEWALL
Transfer of Thermal Unbond Pattern To right sidewall area



TREAD

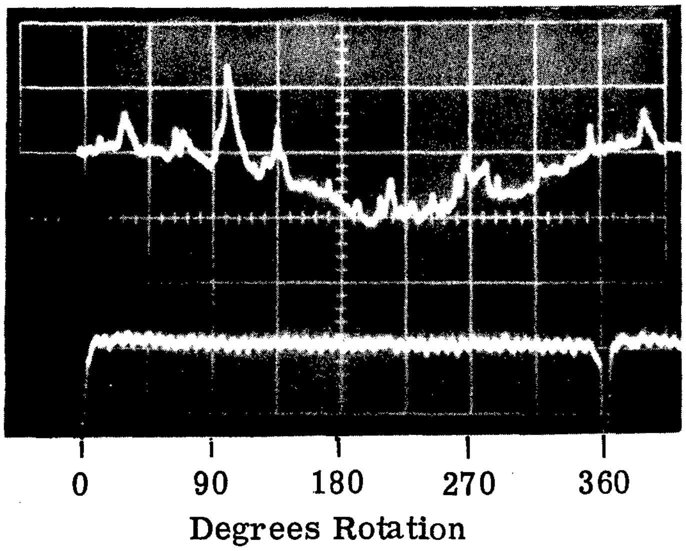
Unbonds Not Detected



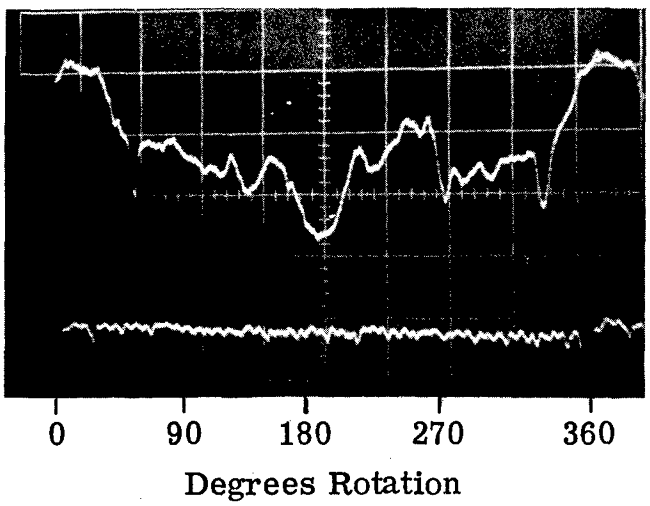
LEFT SIDEWALL
Two Unbonds Located At 90^o & 180^o Each Unbond 4 Square Inches Area

Two Unbonds Located at 90^o & 180^o At Shoulder Edge of Left Sidewall

Figure 8 - Example of Thermal Transfer



Small Active
Heat Producing
Unbond At 95°

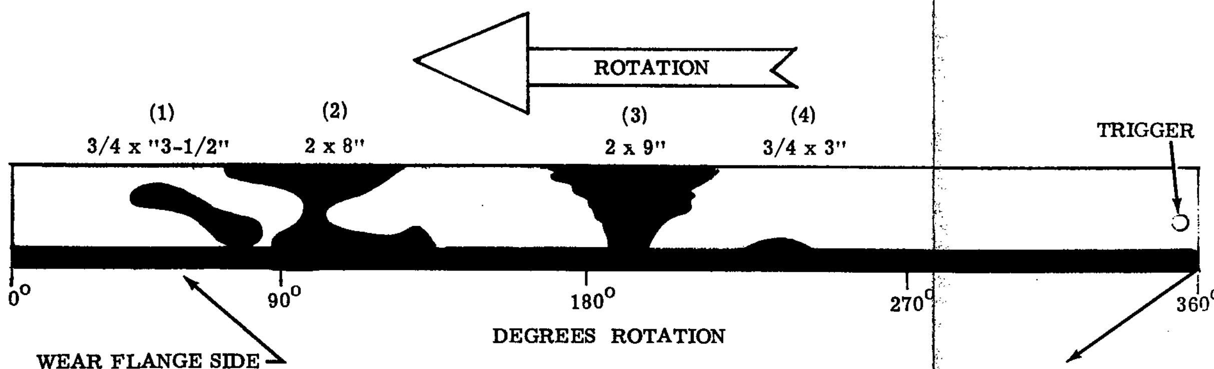


Moderate Size
Dormant Unbond
(Cold) at 180°

Figure 9 - Example of Active and Dormant Unbond Interface Defect

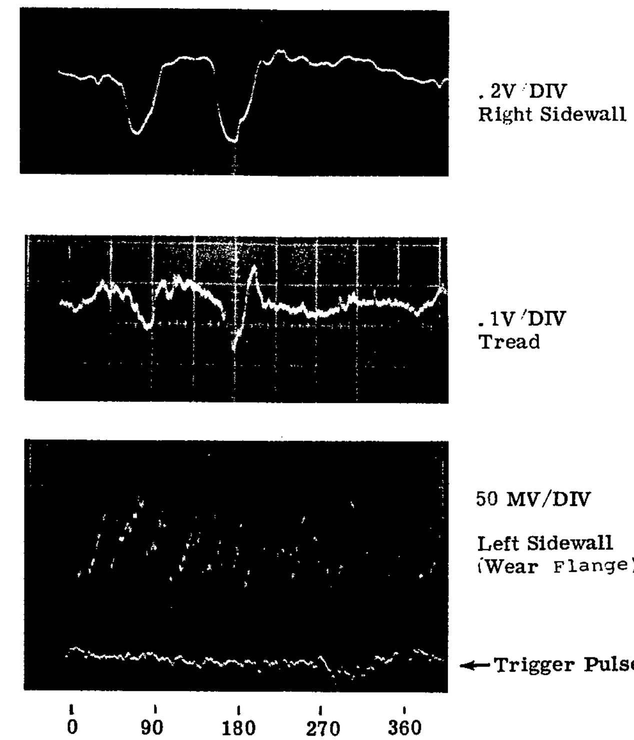
1of2

SPECIMEN NO. 5 **M-113 ROAD WHEEL**



Description of Defects: Separated Completly Over Wear Flange

(1) Unbond
(2) Erosion
(3) Unbond
(4) Unbond
(5) Unbond Along 300° Wear Flange

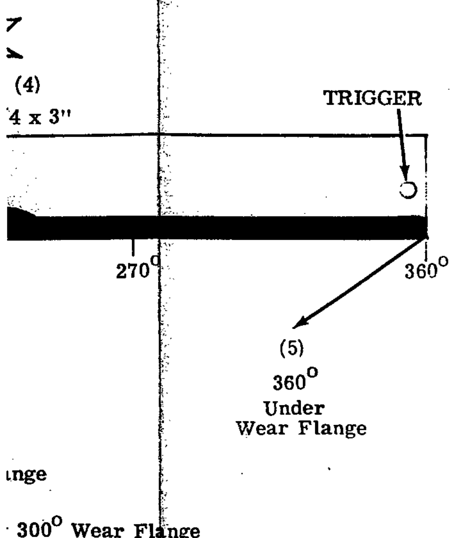


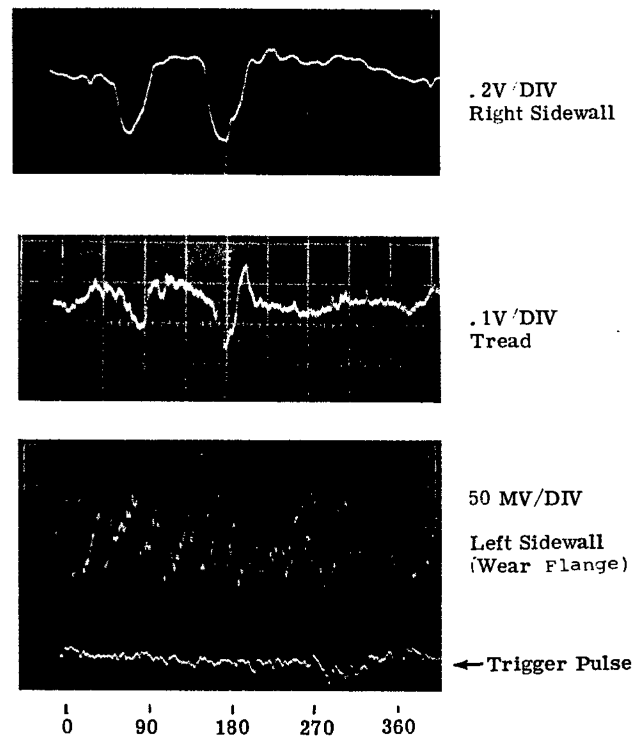
Thermal Profiles

Figure 10 - Stripped Rubber Tread Interface

2 of 2

M-113 ROAD WHEEL





Thermal Profiles

Erosion Caused By Road Debris
Forced Past Wear Flange

Optical Trigger

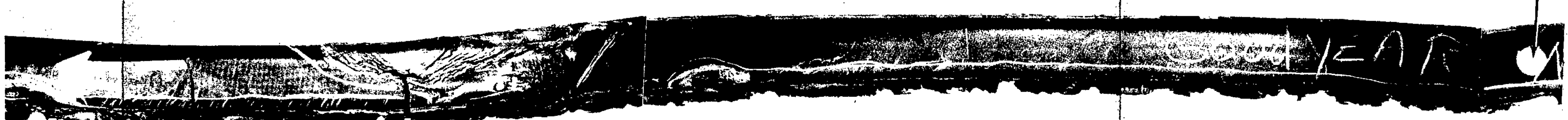
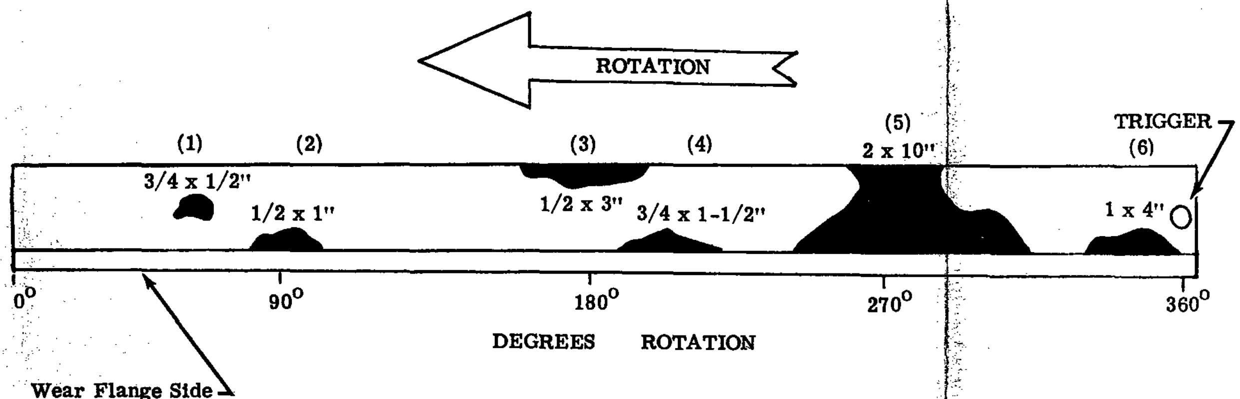


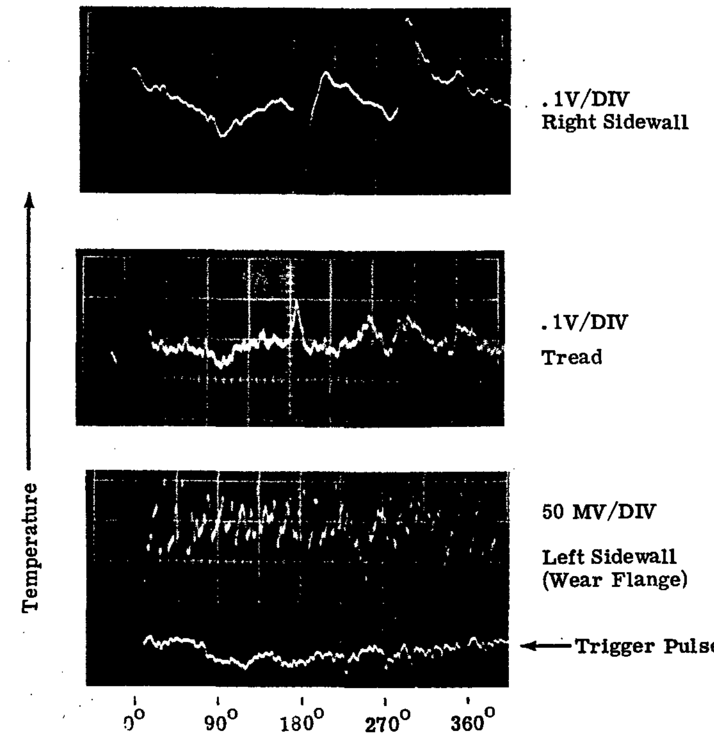
Figure 10 - Stripped Rubber Tread Interface

SPECIMEN NO. 7 M-113 ROAD WHEEL



Description of Defects:

(1)	Unbond	(4)	Erosion
(2)	Erosion	(5)	Gross Unbond
(3)	Erosion	(6)	Erosion



Thermal Profiles

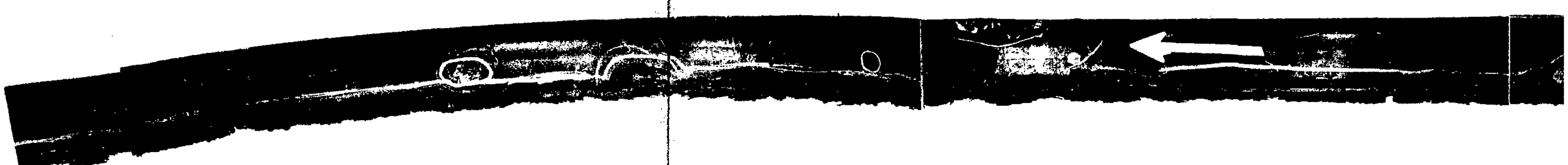
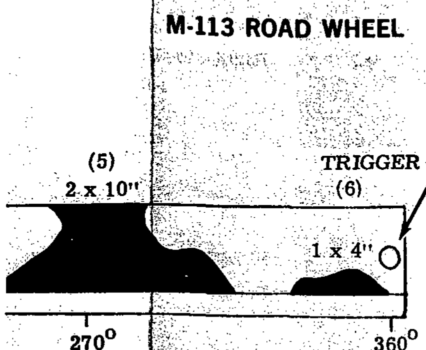
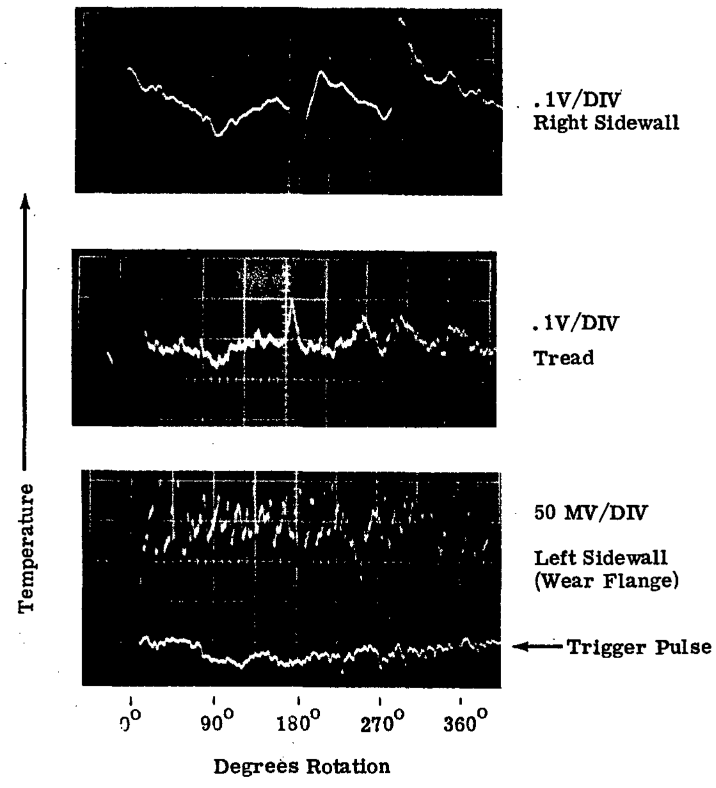
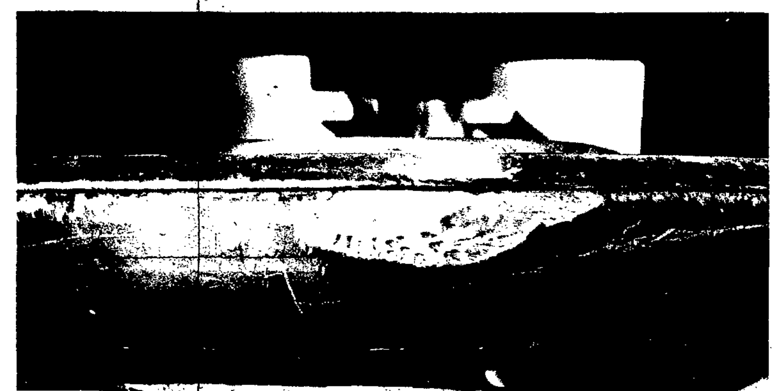


Figure 11 - Stripped Rubber Tread Interface





Thermal Profiles



Erosion - Defect Location (3)

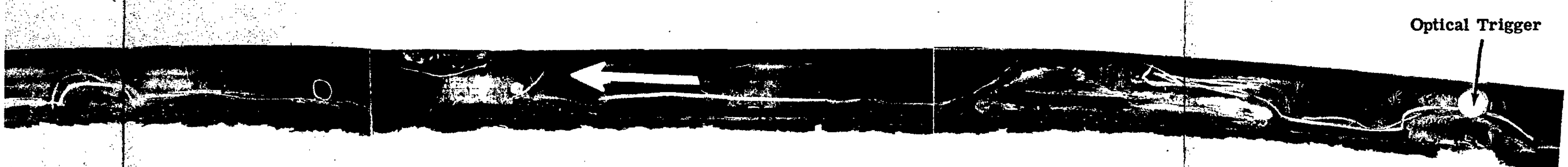
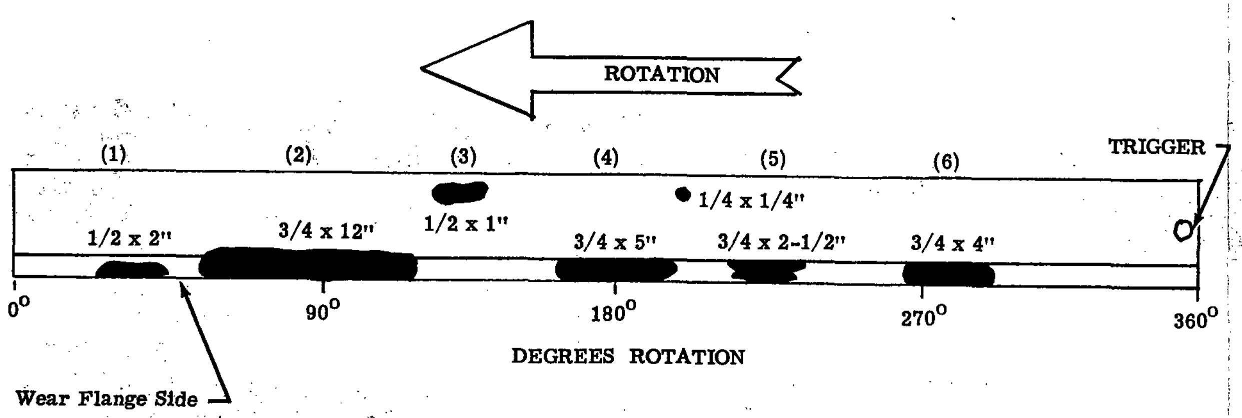


Figure 11 - Stripped Rubber Tread Interface

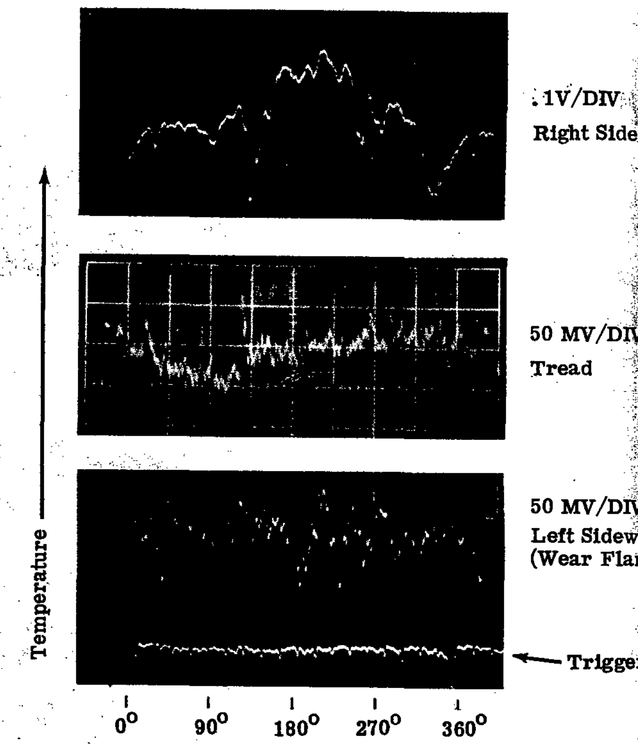
SPECIMEN NO. 8

M-113 ROAD WHEEL



Description of Defects:

(1) Unbond
(2) Unbond Due To Adhesive Feathering
(3) Track Guide Damage
(4) Unbond At Wear Flange
(5) Unbond At Wear Flange
(6) Unbond At Wear Flange



Thermal Profiles

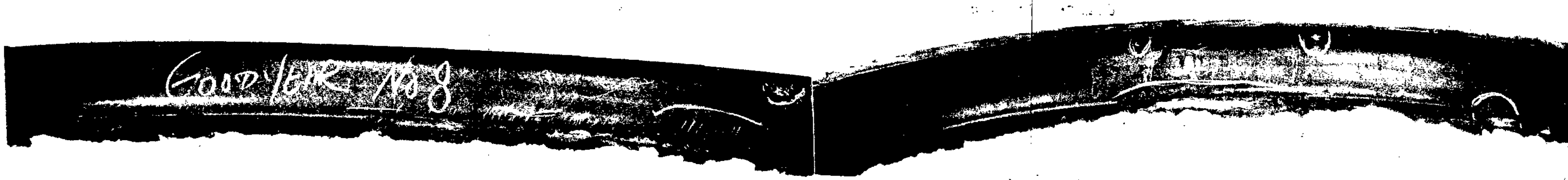
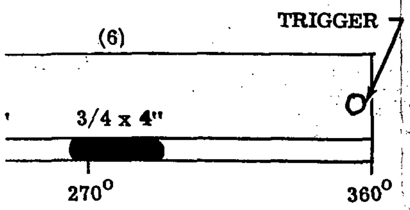
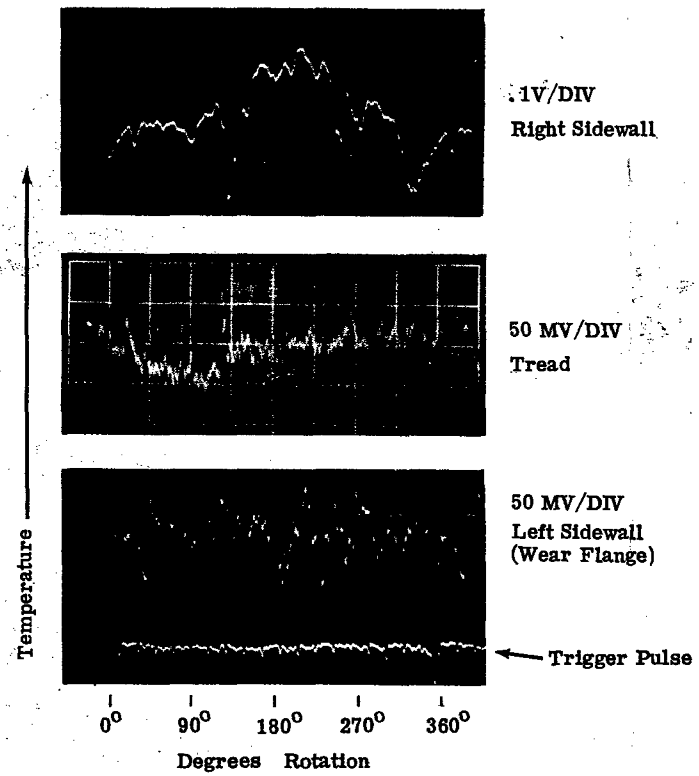


Figure 12 - Stripped Rubber Tread Interface

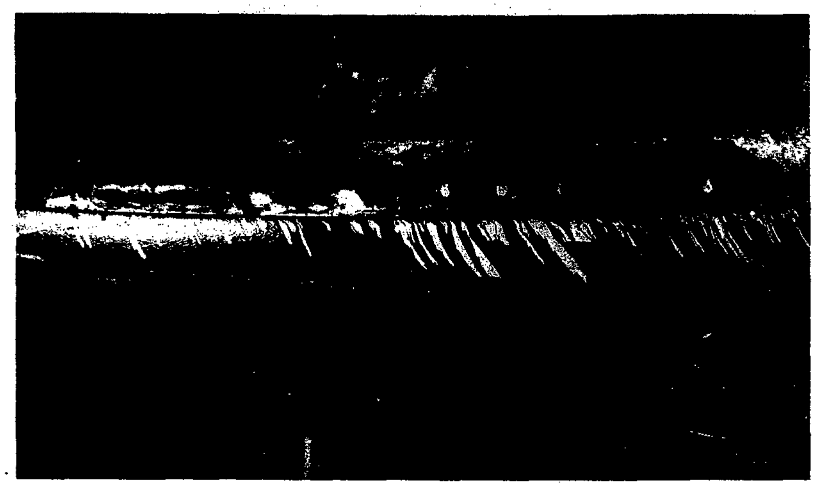
M-113 ROAD WHEEL



Feathering



Thermal Profiles

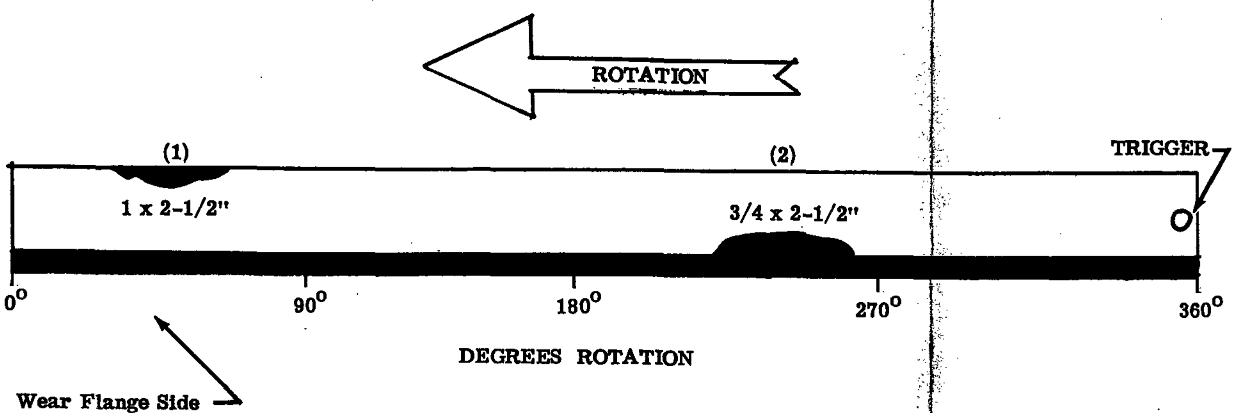


Feathering of Adhesive Along Wear Flange (2)

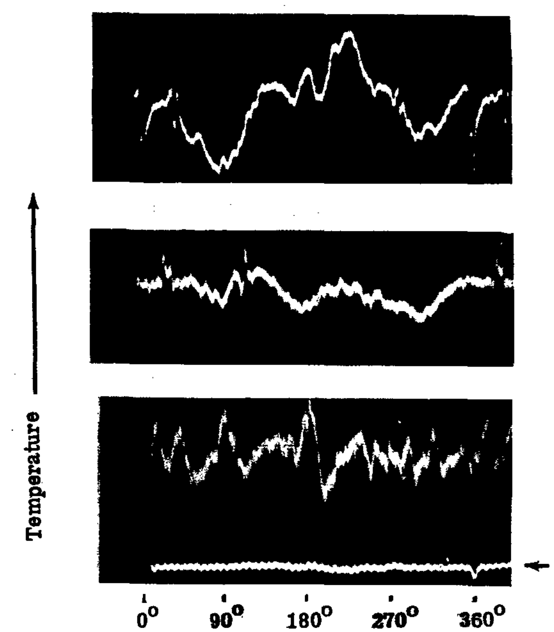
Figure 12 - Stripped Rubber Tread Interface

1of2

SPECIMEN NO. 12 M-113 ROAD WHEEL



Description of Defects: Unbond Along Length of Wear Flange
(1) Unbond
(2) Unbond



Thermal Profiles

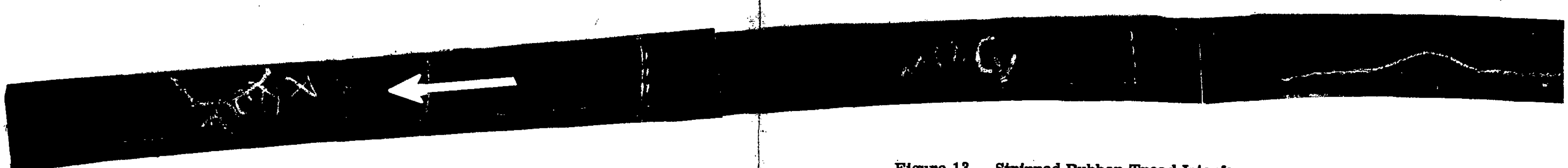
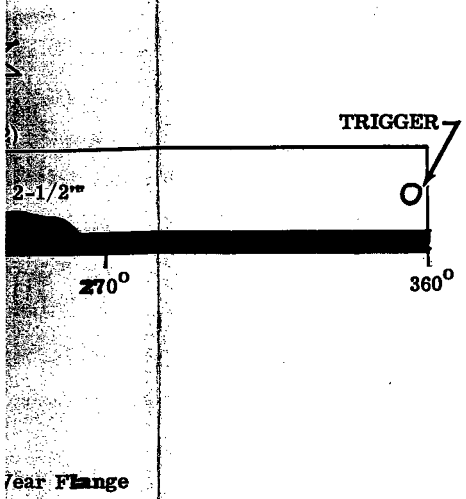
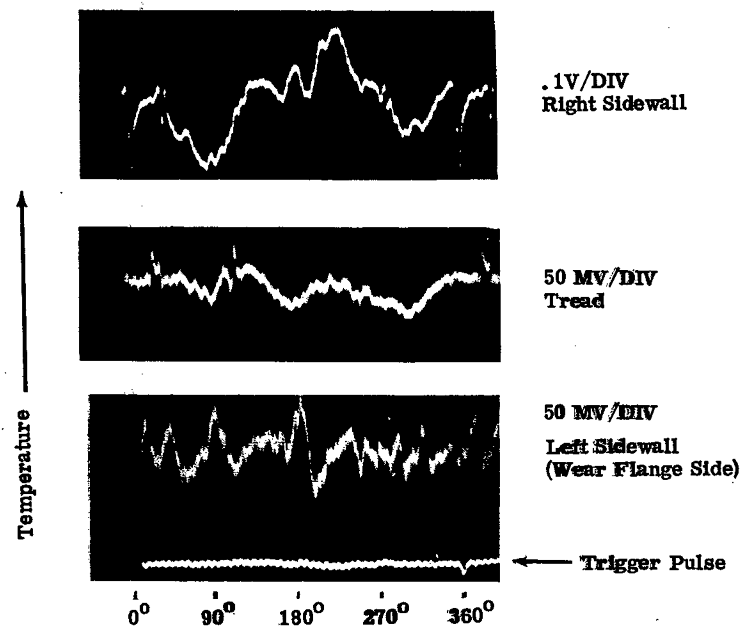


Figure 13 - Stripped Rubber Tread Interface

2 of 2

M-113 ROAD WHEEL





Thermal Profiles

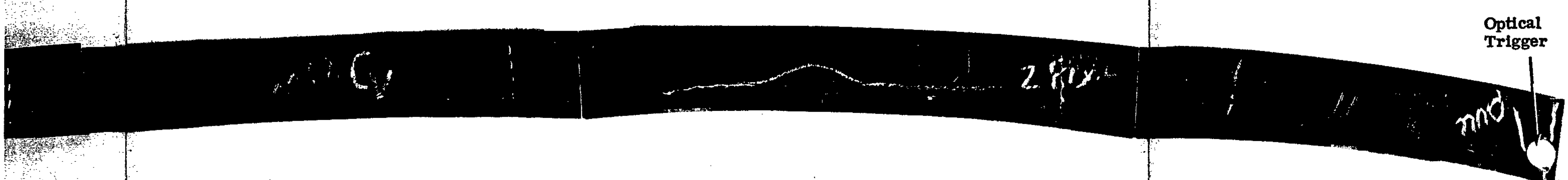
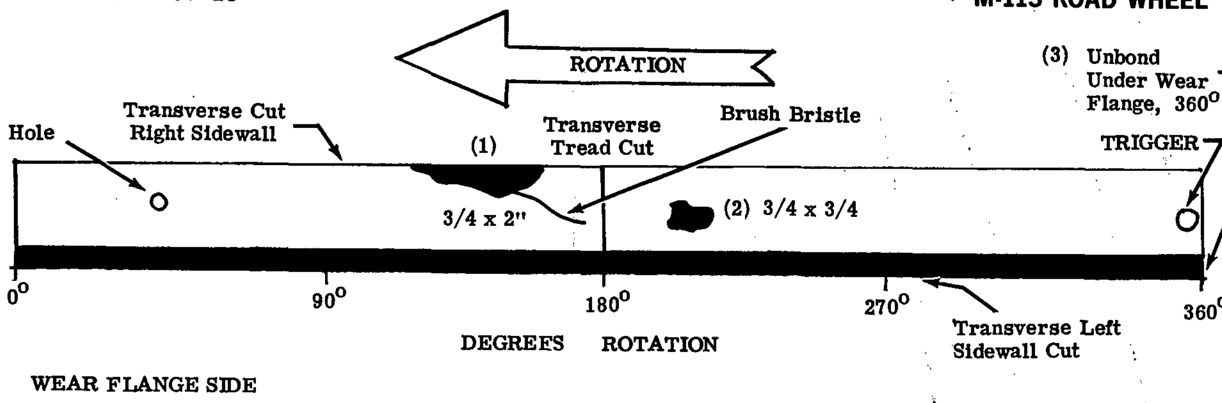
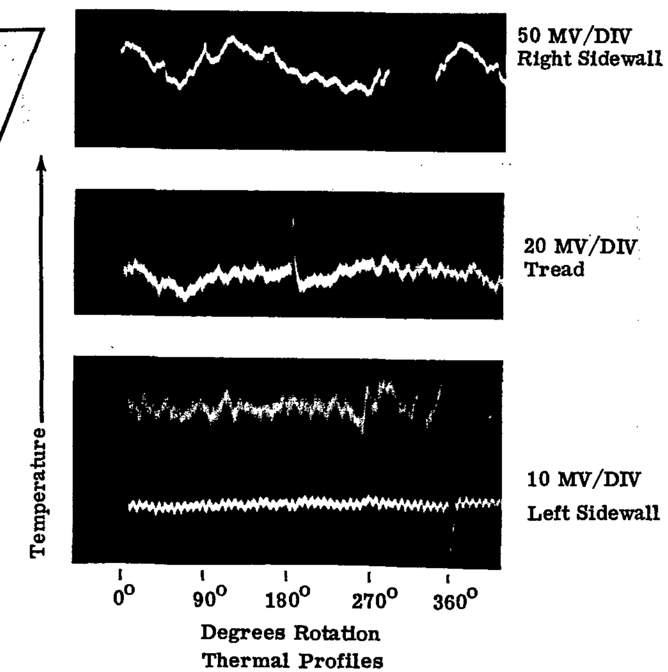


Figure 13 - Stripped Rubber Tread Interface

SPECIMEN NO. 13 **M-113 ROAD WHEEL**





Description of Defects: Unbond Along Entire Length of Wear Flange
(1) Unbond

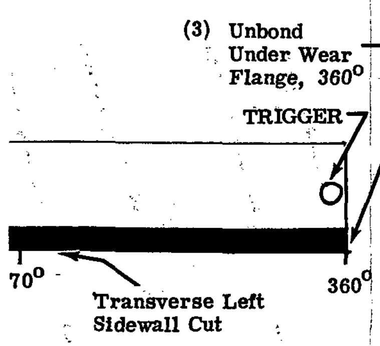
Simulated Defects:

Needle Hole - Acetone Injected At Interface	(45°)
Transverse Left Sidewall Cut	(90°)
Transverse Tread Cut	(180°)
Transverse Right Sidewall Cut	(270°)

Figure 14 - Stripped Rubber Tread Interface

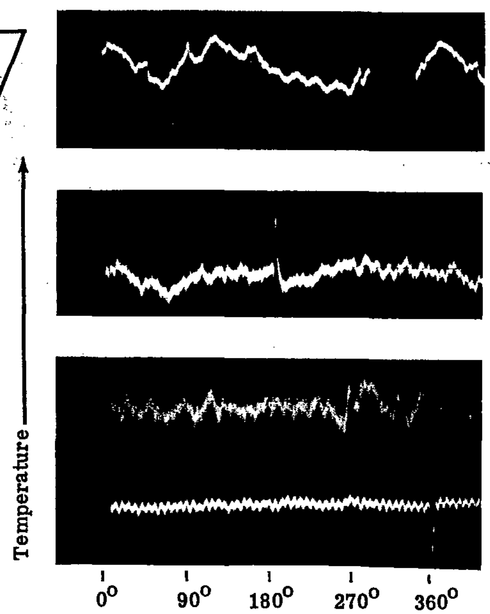
2of2

M-113 ROAD WHEEL

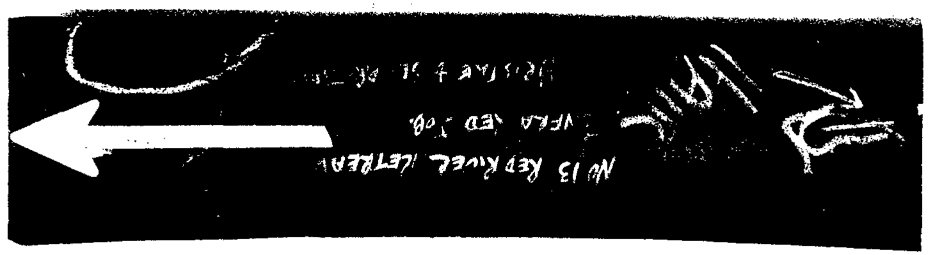


.r Flange

.ce (45°)
(90°)
(180°)
(270°)



Degrees Rotation
Thermal Profiles



Brush Bristle (Hair) at 175°

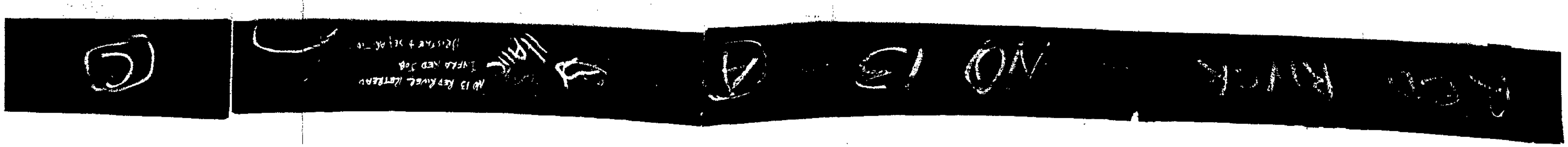
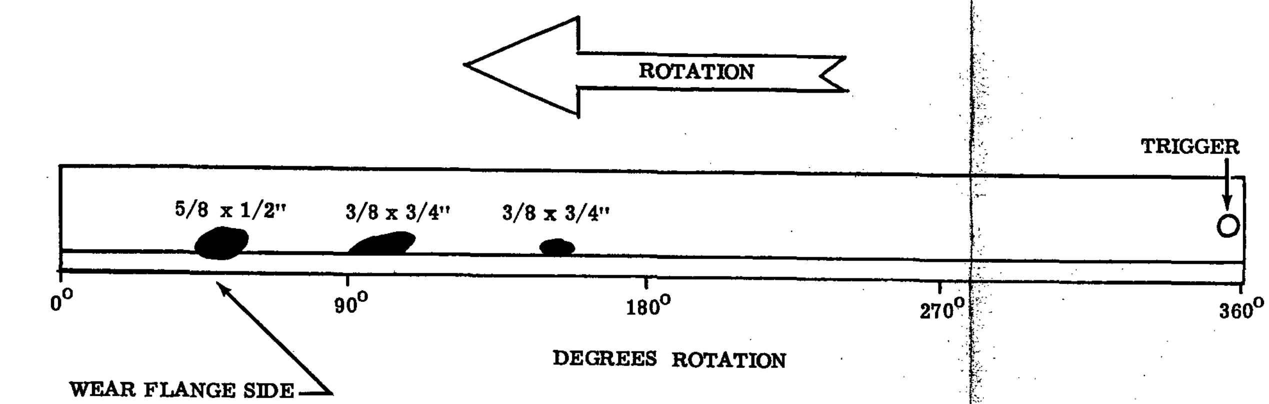
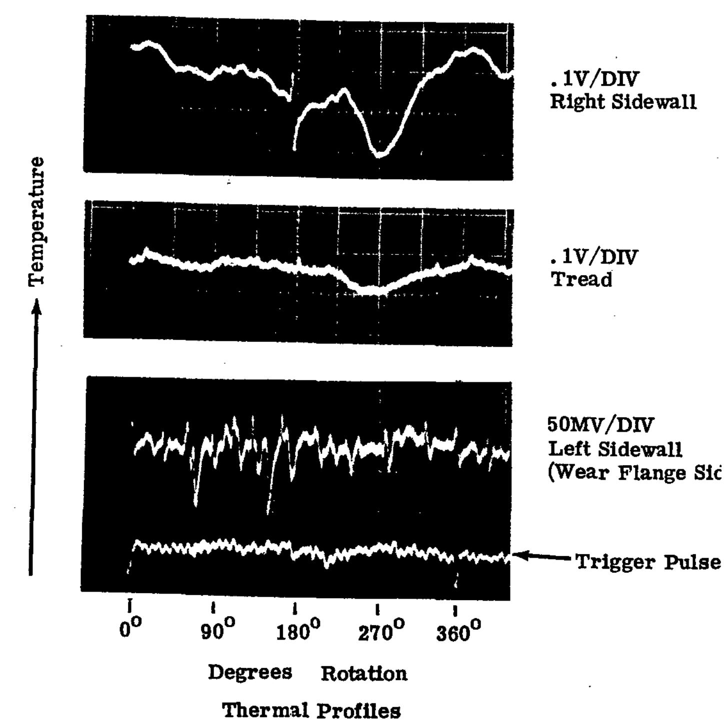


Figure 14 - Stripped Rubber Tread Interface

SPECIMEN NO. 15 M-113 ROAD WHEEL



Description of Defects: All Defects Less Than 1 Sq. In.



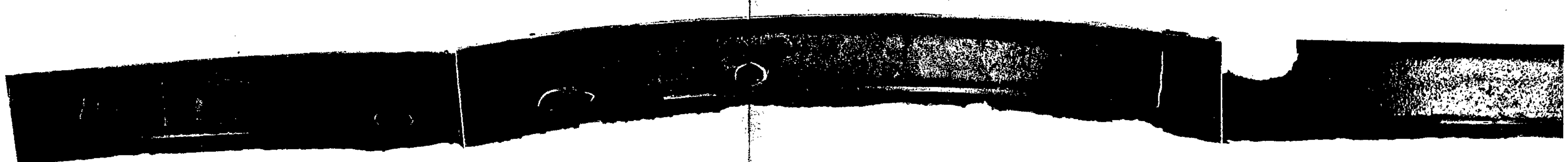
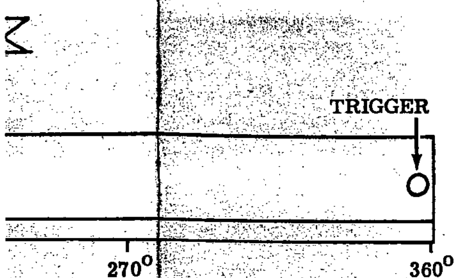


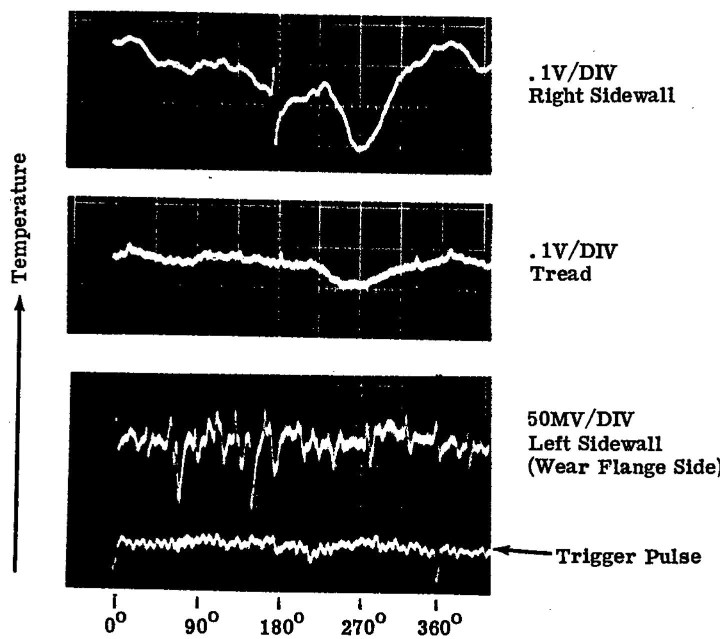
Figure 15 - Stripped Rubber Tread Interface

2of2

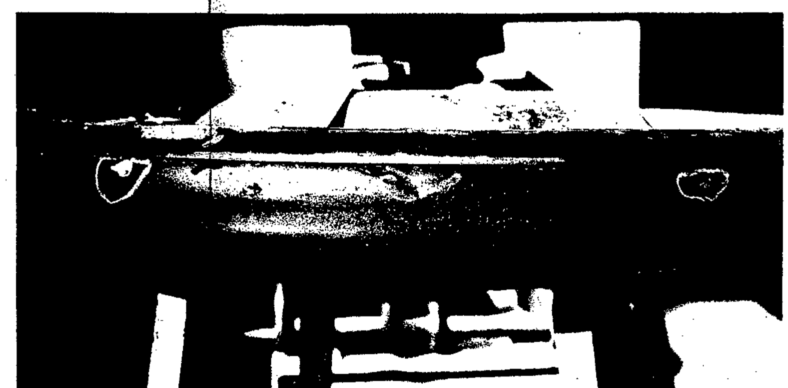
M-113 ROAD WHEEL



han 1 Sq. In.



Thermal Profiles



Track Guide Damage

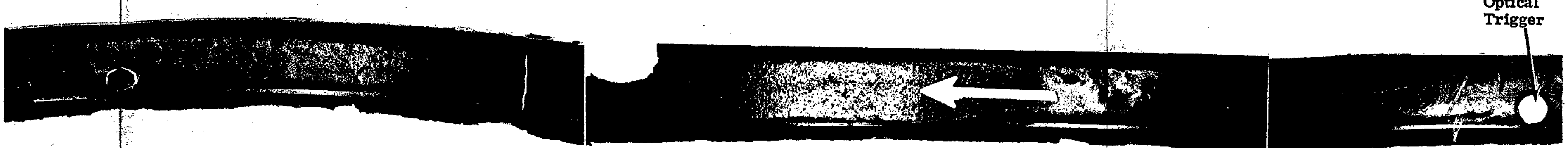
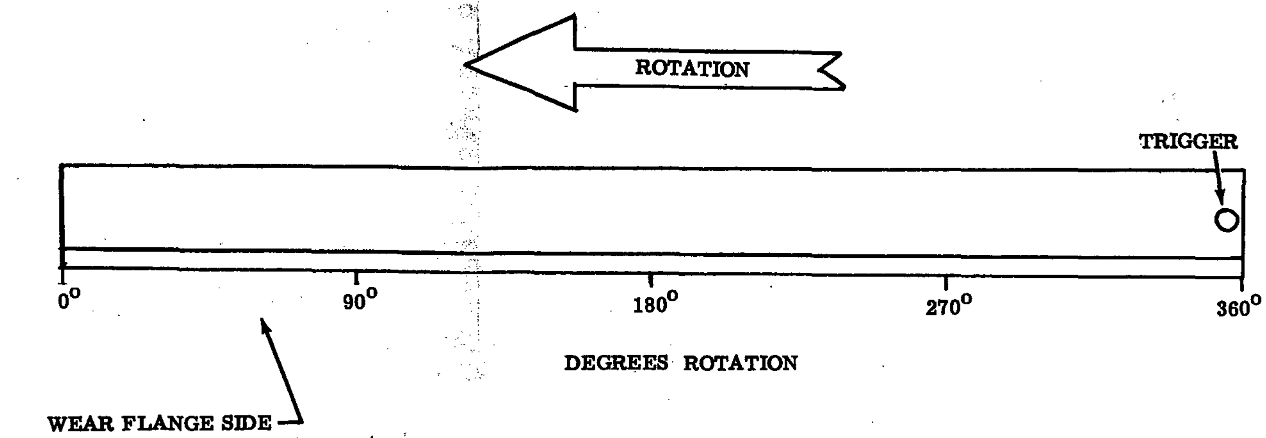
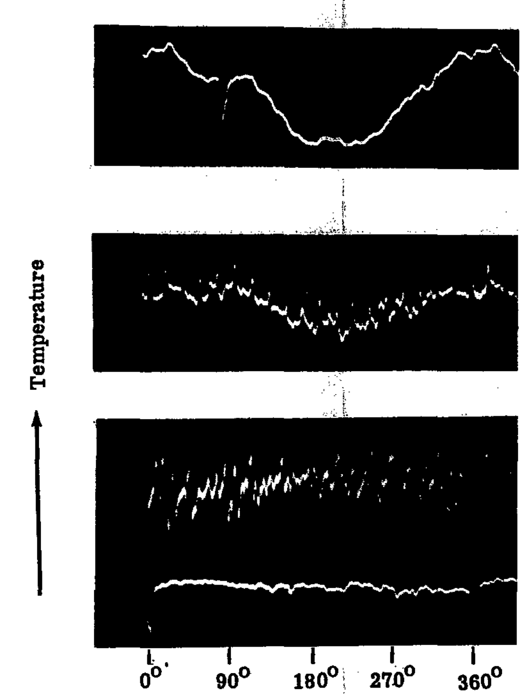


Figure 15 - Stripped Rubber Tread Interface

SPECIMEN NO. 16

M-113 ROAD WHEEL

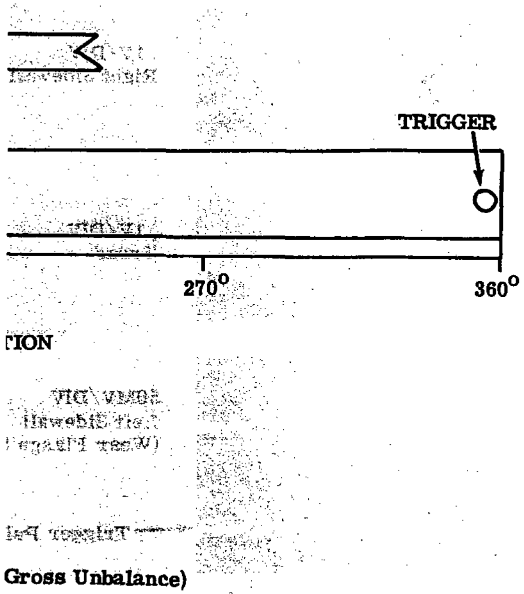




NO DEFECTS   Wheel Out of Round (Gross Unbalance)

Figure 16

M-113 ROAD WHEEL



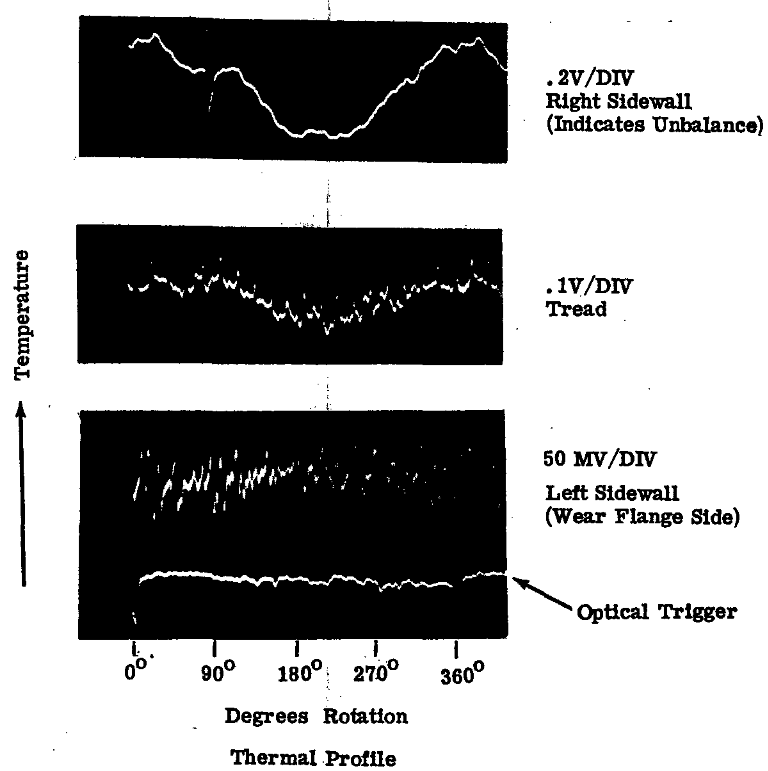
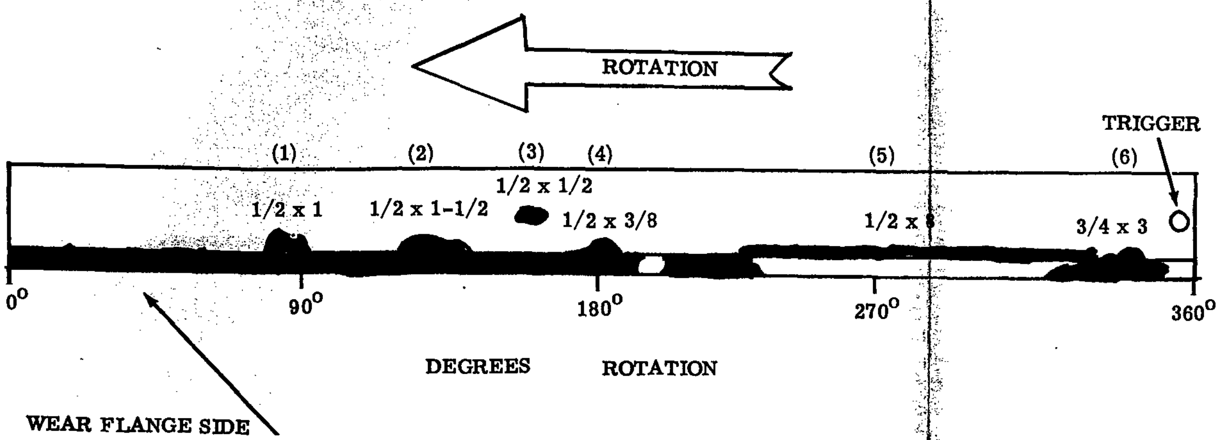


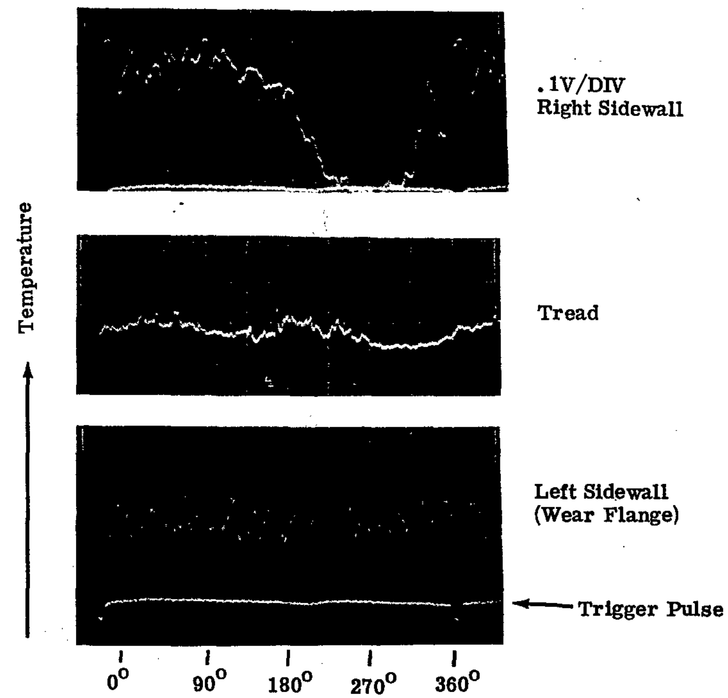
Figure 16

SPECIMEN NO. 19 **M-113 ROAD WHEEL**



Description of Defects:

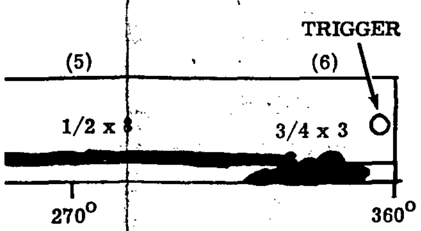
(1) Unbond
(2) Unbond
(3) Track Guide Damage
(4) Unbond
(5) Unbond
(6) Unbond



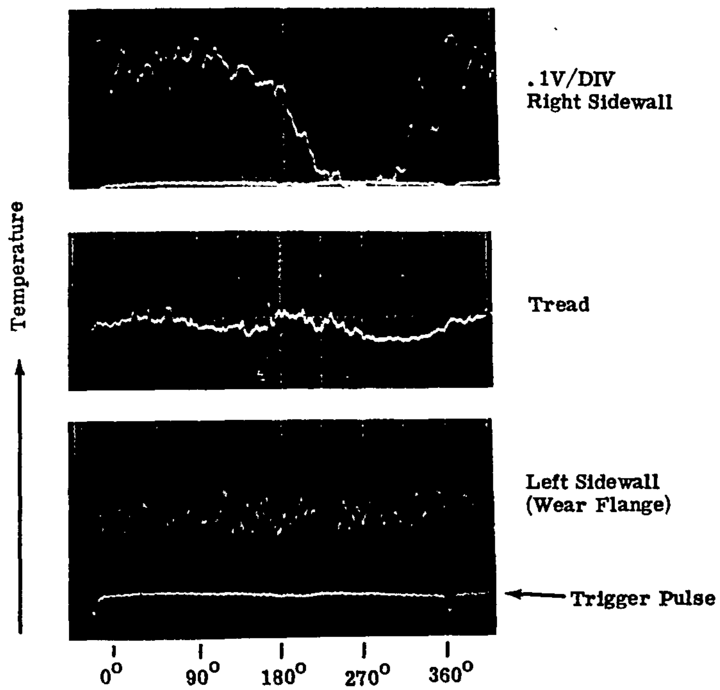
Thermal Profiles

Figure 17 - Stripped Rubber Tread Interface

M-113 ROAD WHEEL



amage



Thermal Profiles

Track Guide Damage, Defect No. 2 and 3

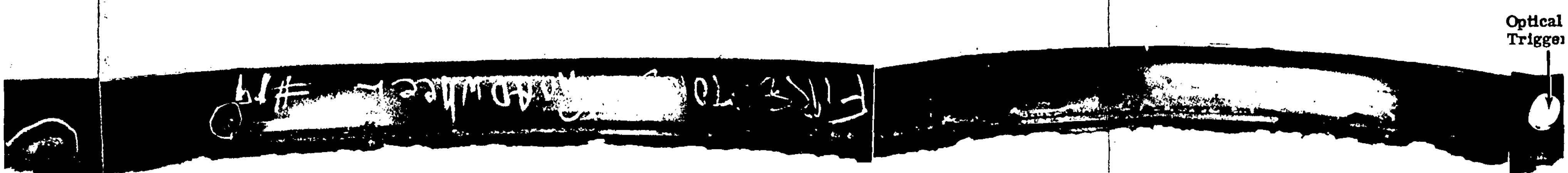
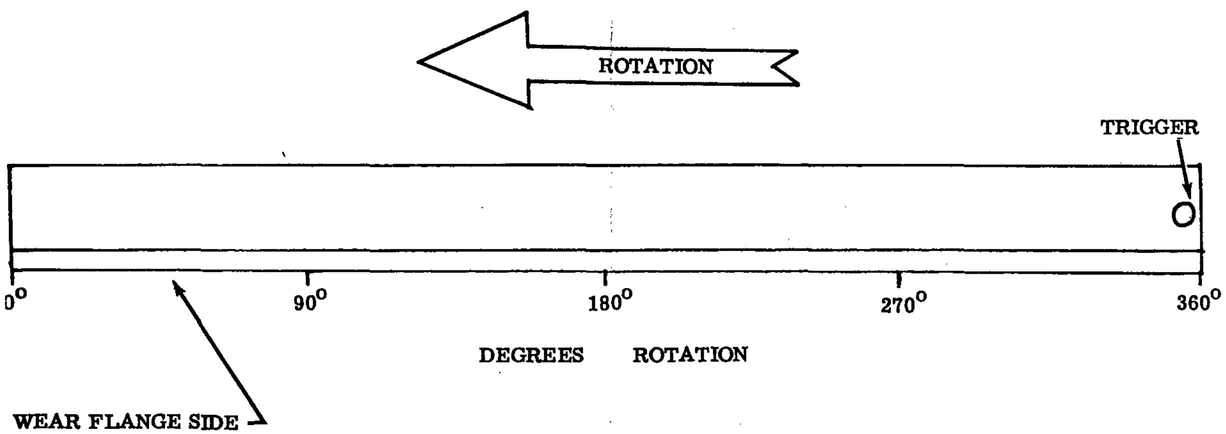


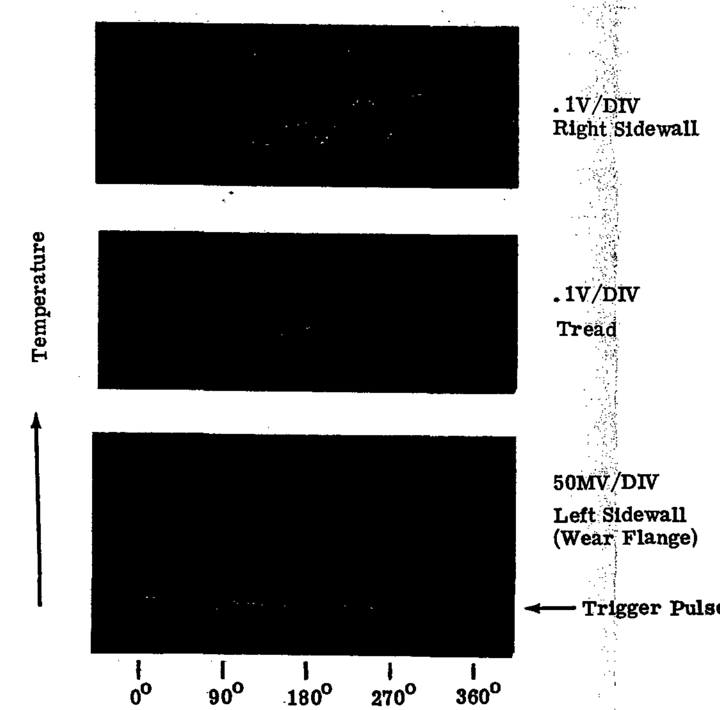
Figure 17 - Stripped Rubber Tread Interface

SPECIMEN NO. 20

M-113 ROAD WHEEL



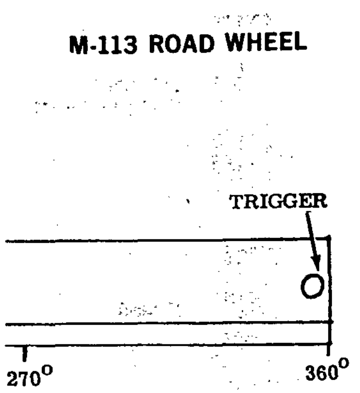
No Defects Developed During Drum Test

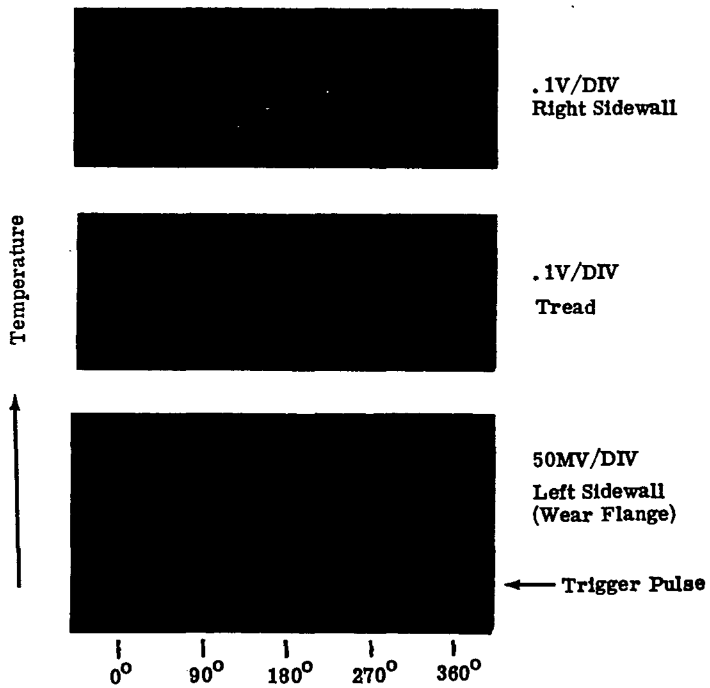


Degrees Rotation

Thermal Profiles

Figure 18 - Stripped Rubber Tread Interface





Degrees Rotation

Thermal Profiles

Feathering of Adhesive Along
Wear Flange

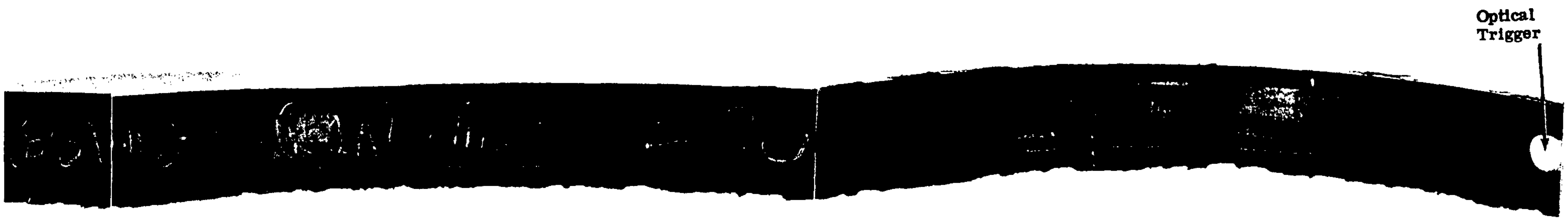
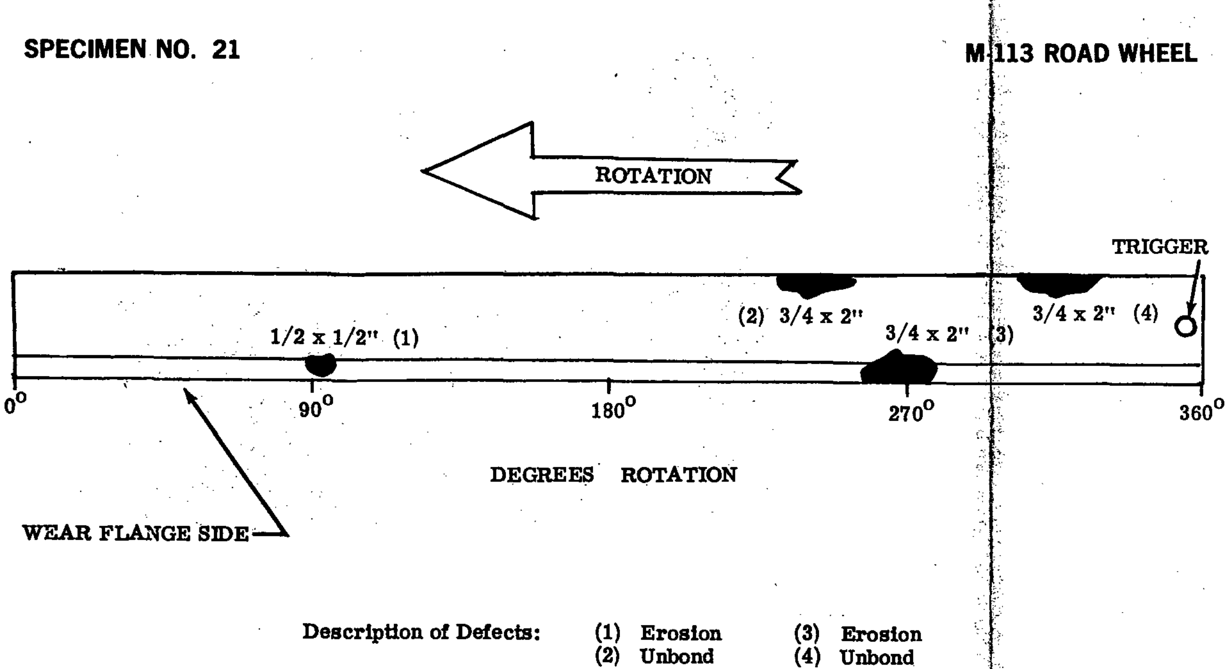
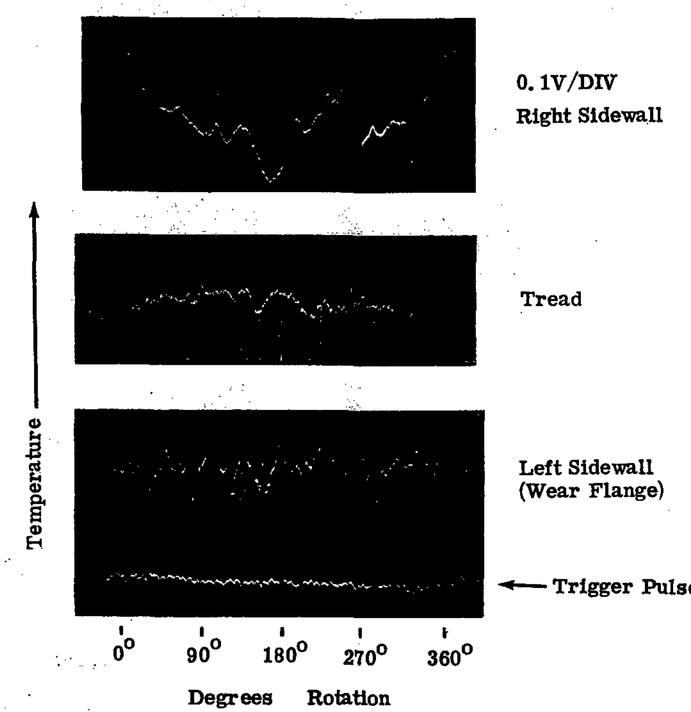


Figure 18 - Stripped Rubber Tread Interface





Thermal Profiles

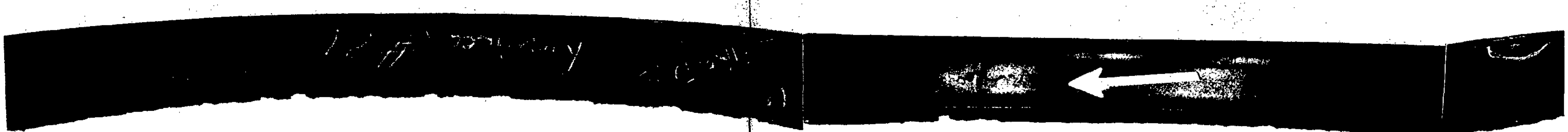
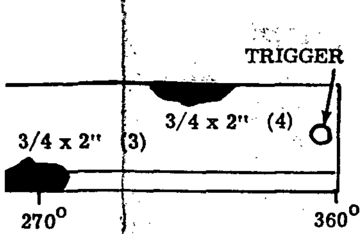
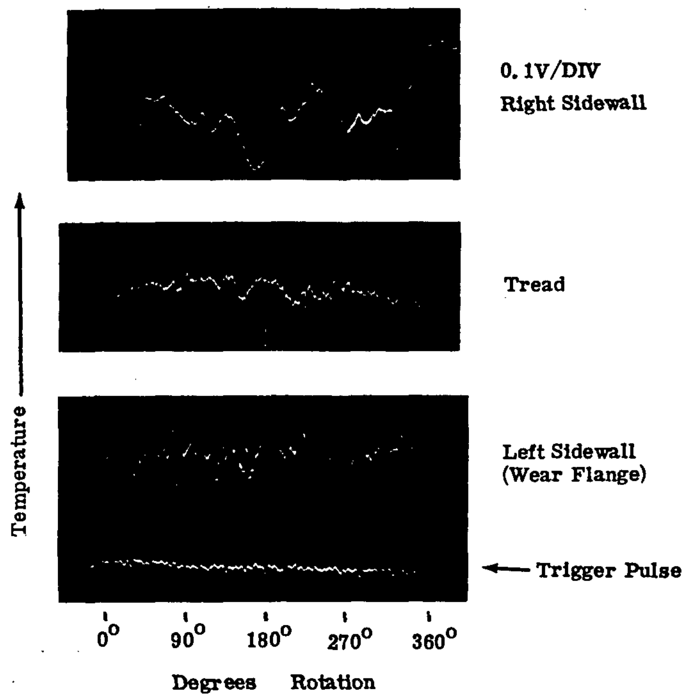


Figure 19 - Stripped Rubber Tread Interface

M-113 ROAD WHEEL





Thermal Profiles

Erosion - Defect Location (1)

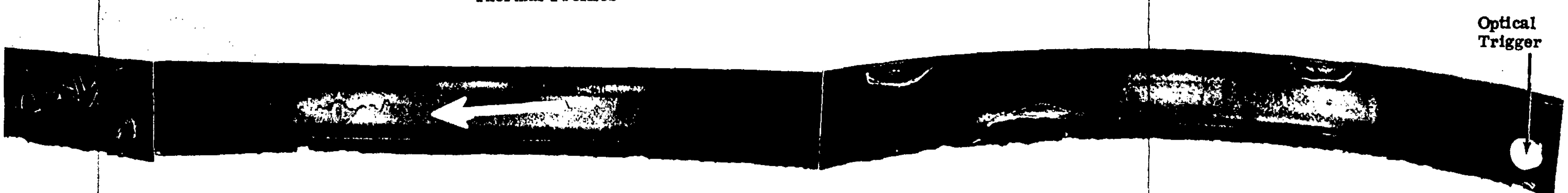
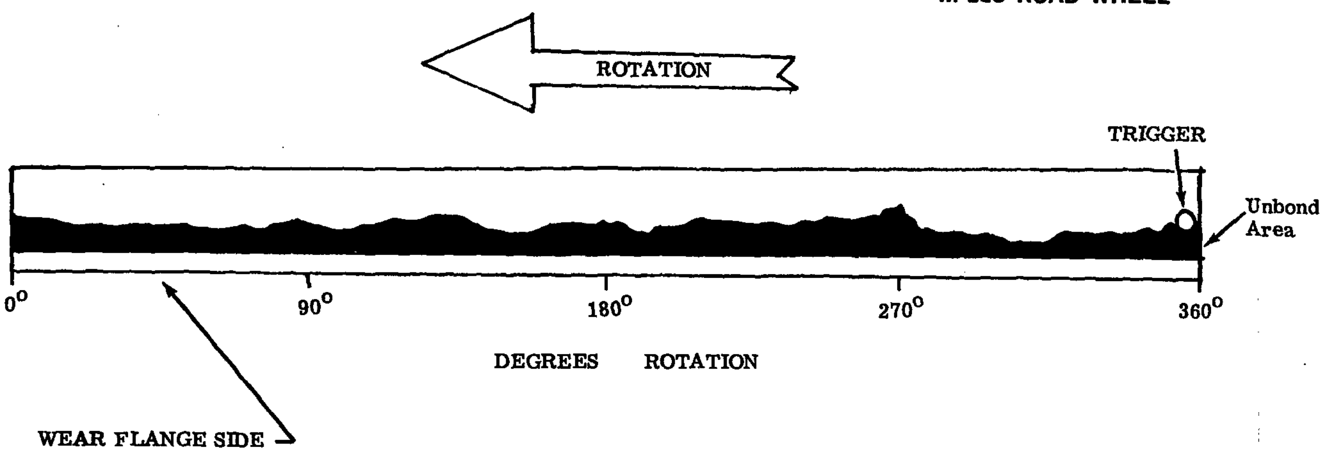


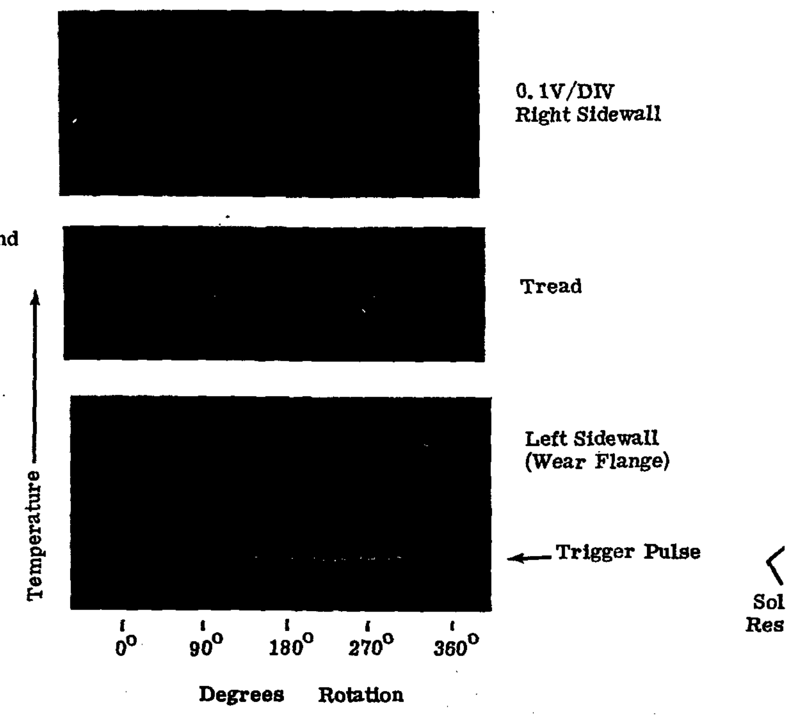
Figure 19 - Stripped Rubber Tread Interface

SPECIMEN NO. 24

M-113 ROAD WHEEL



Description of Defect: 360° Unbond 3/4 To 1-1/2 Wide



Thermal Profiles

Figure 20 - Stripped Rubber Tread Interface

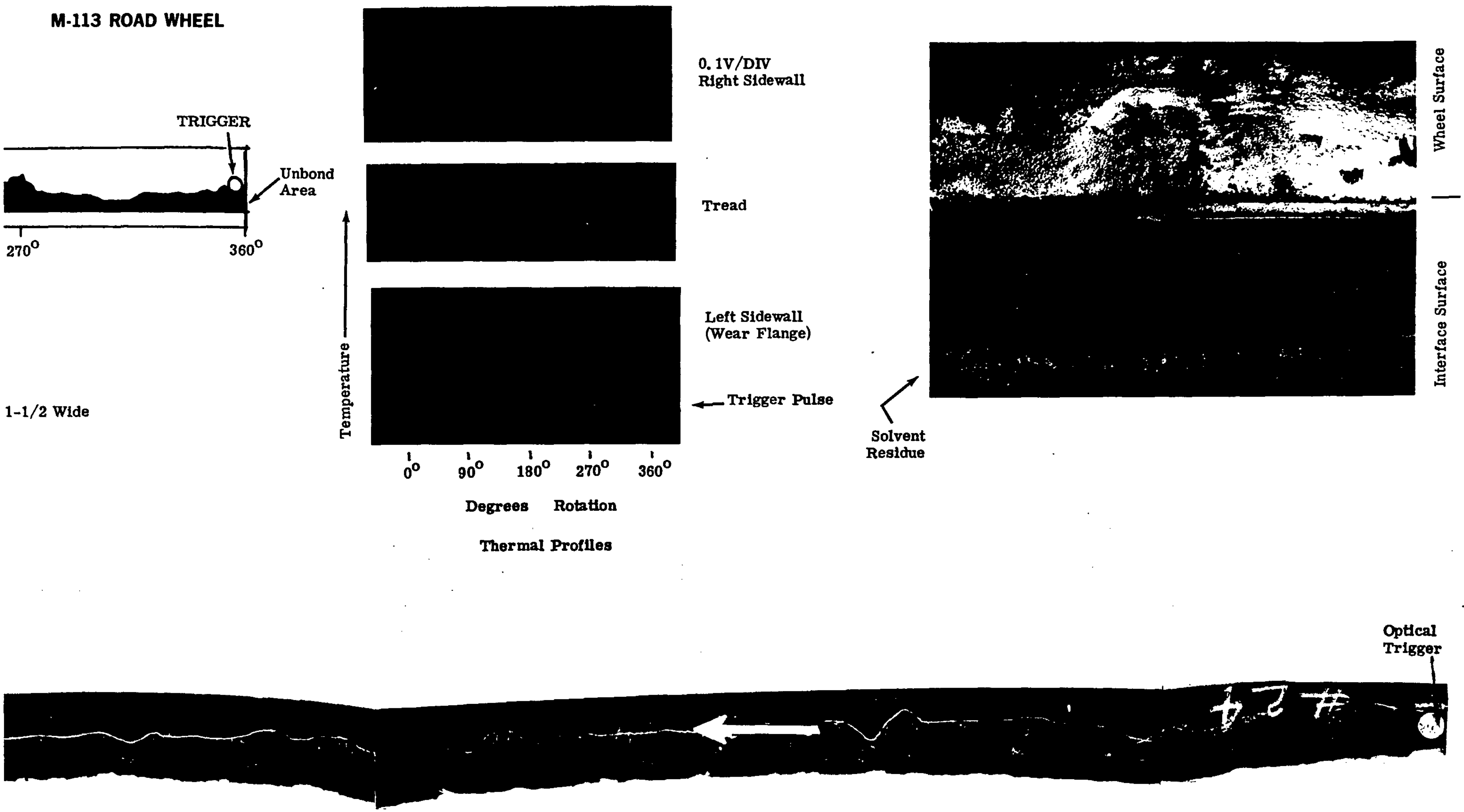


Figure 20 - Stripped Rubber Tread Interface

EXHIBIT P-16 (Part I) DATE 1 March 1972

PRODUCTION ENGINEERING MEASURES (PEM) PROJECT

RCS CSGLD 1125 (RI)

1. Project No.__________ 2. PEMA__________ 3. COST 20.1K

4. Title: Infrared Diagnosis of Road Wheels

5. Facility: U.S. Army Tank Automotive Command
ATTN: AMSTA-RGD, Warren, Michigan 48090

6. Purpose: To apply infrared tire diagnostic techniques developed during FY 70 project on pneuma tic tires to evaluation of solid rubber road wheels. Utilization of infrared techniques of analysis is based on generation of a "thermal fault signature" which associates various temperature profiles with the various wheel defects. Previous experience on IR tire analysis indicates a possibility of detecting the following types of defects in road wheels:

   a. Unbonds between rubber/adhesive and metal wheel

   b. Porosity in rubber

   c. Crack or chunking in rubber

   d. Non-uniform rubber characteristics

   It does not appear from a thermal conductivity analysis of heat transfer that low bonds or bond strength can be determined from the IR technique of inspection.

   In addition, part of this program will include a study of what constitutes a defect in road wheels. The above listed a. through d. classifications may not constitute all types of defects known to degrade the performance of the wheel.

   The test program will involve analysis of new and rebuilt road wheels from M113 class vehicles. The wheels will be run on a tire dynamometer at 10 and 30 MPH at specification loads. Three IR sensor heads will view left side, right side and tread areas of the wheel. Instrumentation will be updated to improve low frequency response for 10 MPH wheel speeds.

7. Objective/Benefits:

a. This program will support the M113 and M551 class of vehicles which utilize standard 24 inch road wheels. It will also provide assistance to rebuild depots in the form of test guidance for wheel inspection after rebuild.

b. The goals of this program are as follows:

(1) Determine type and size of road wheel defects which degrade wheel longevity or performance.

(2) Determine by laboratory tests infrared/thermal profiles of road wheels in operation and isolate to "real" defect classification.

(3) Derive preliminary information on an IR specification for road wheel acceptance tests.

8. Item(s) Supported:

Solid rubber road wheels, 24" for M113 and M551 vehicles, also adaptable to M60 wheels.

9. Current and Projected Required Requirements:

Standard specification tests for road wheels require dynamometer testing with destruction of the wheel to determine bond strength. A NDT method of analysis will reduce the number of wheels destroyed in test and allow defect classification to determine wheel integrity.

10. Description of Work:

a. An infrared method of road wheel analysis is a non-contact means of remotely measuring the temperature gradients in a revolving wheel under load. Unique and non-uniform temperature patterns observed in the wheel are descriptors which point to developing or insipid defects. Previous similar work on pneumatic tires is reported in USATACOM TR 11154. Current ongoing research on IR tire analysis is in progress on PEMA Project #9431.

b. This proposed effort will utilize instrumentation and techniques acquired on the previous efforts.

11. End products from project

See Inclosure 1.

12. Detailed cost summary:

See Inclosure 2.

13. Time phasing:

See Inclosure 3.

14. Related efforts:

See Inclosure 4.

15. Remarks:

None

END PRODUCTS FROM PROJECT

a. A critical analysis of the use of IR in examining road wheels after rebuild or new manufacture.

b. Type and size classification of defects which degrade wheel performance.

c. Preliminary assessment of an IR specification for road wheel testing.

Inclosure 1

DETAILED COST SUMMARY

COST BY ITEM*

	Government	Contractor	Total
New Instrumentation	0	$ 6500	$ 6500
Equipment Instrumentation	$ 1200	0	1200
Installation	900	0	900
Pilot Production	0	0	0
Procurement Packages	0	0	0
Other (Travel)	850	0	850
TOTAL	$ 2950	$ 6500	$ 9450

COST BY TYPE*

	Government	Contractor	Total
Direct Material	$ 1200	0	$ 1200
Contracted Work	0	0	0
Direct Costs	9500	0	9500
Other Factors	0	0	0
Profit	0	0	0
TOTAL	$ 10700	0	$ 10700

EXPENDITURE BY FISCAL YEAR

	Prior FY		Budget FY		Future FY
	FY 70	FY 71	FY 70	FY 71	FY 71
PEMA	0	0	0	0	0
R&D	$ 2000	0	0	0	$ 20.1K

* Including O. M. of A. (operating expense) Current hourly rate is $ 28. 67.

Inclosure 2

TIME PHASING*

Design and installation of test	30 days
Calibration and instrumentation checks	10 days
Defect classification studies	60 days
Road wheel operation tests	90 days
Data analysis	15 days
Report	30 days

* Exact time phasing to be established at test approval time.

Inclosure 3

RELATED EFFORTS

A brief previous R&D test on two experimental road wheels established feasibility of the IR technique. Other related efforts by FMC, contractor on the M113 vehicle, also confirmed possible use of IR method of test to road wheels.

Inclosure 4

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13. ABSTRACT

Twenty-six used and rebuilt solid rubber road wheels were examined by an infrared temperature profiling technique during drum test exercise. The IR method was evaluated as a nondestructive means of predicting road wheel integrity by analysis of the circumferential temperature profile. The effectiveness of the temperature profiling method was determined by stripping the rubber from each wheel and visually evaluating the bond interface and rubber tread. Known defects comprising tread and sidewall cracks and rubber-metal interface delamination were artificially induced into rebuilt road wheels to evaluate the examination method. Left and right sidewall and tread area were examined simultaneously by use of three sensor heads which were mounted in a test rig positioned around the test wheel. Results indicate that the IR test technique has a capability of detecting cracks and chunking in the rubber tread, gross unbonds and interface delaminations, and large area entrapped foreign objects at the rubber-to-metal interface. Low bond strength and small unbond areas less than 1 square inch were not detected. Defects located along the left sidewall interface area were more difficult to sense due to the wear flange and high thermal coupling into the metal sidewall which dissipated tread developed heat.

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